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AN ECONOMIC MODEL FOR UNDERSEA MINING

A THESIS

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AN ECONOMIC MODEL FOR

UNDERSEA MINING

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SUMMARY

The purpose of this work is to construct an economic model which can be used to analyze the economic potential of various undersea mineral deposits. This economic model, which is presented in Chapter V of this work, is based on the analyses which were conducted in the first four chapters. These analyses were conducted to determine the parameters which should be included in the economic model.

After the model is constructed, it is tested with data characteristic of Pacific Ocean manganese nodule deposits. Four tests are conducted with the model for the purpose of determining the economic importance of various parameters. The results of these tests indicated that the market prices of the minerals which were produced from the manganese nodule deposit were the most important economic parameters. Analysis of the results of these tests also indicated there may be an economic incentive to mine Pacific Ocean manganese nodules at this time, but financing the high risk mining investment may be difficult.

CHAPTER I

INTRODUCTION AND OBJECTIVES

Introduction

Roughly 71 per cent of the earth's surface has remained relatively untapped by man in his search for mineral resources. This vast area of approximately 139,440,000 square miles is covered by the oceans of the world and is believed to contain many of the resources needed by man in the future. One expert (17) believes that by 1990 the mineral resources of the ocean will be supplying the bulk of the free world's consumption of manganese, nickel, copper, cobalt and many other minerals. The accuracy of this prediction depends on the development of economic and technological systems for extracting the minerals from their ocean environment. These ocean systems will have to compete with land based mining operations which have developed from centuries of mining experience.

The existence of established land based mining systems will prove both an aid and a deterrent to pioneer ocean mining systems. The knowledge gained and the technology developed from land mining will certainly be applied to ocean mining and could result in operations free of traditional mining inefficiencies. The absence of sufficient knowledge concerning the ocean environment and its effect on ocean mining systems, however, may result in other inefficiencies peculiar to the ocean system. The initial cost of the ocean mining system will be greater than a similar land based system, and therefore, to be economically justified the ocean system must provide greater operating efficiencies. Higher throughput, greater concentrations of minerals, and reduced transportation costs could be some of the advantages which make the exploitation of an ocean deposit economically feasible. This, of course, depends on the ocean deposit involved. In the case of phosphate rock deposits which are found off the coast of several countries, the transportation cost is one of the prime economic factors. Phosphate is a relatively low priced mineral and the delivered price may sometimes be double the mine site price. For areas which are void of land phosphate deposits but have nearby ocean deposits, the savings in transportation costs may justify the development of ocean phosphate mining systems.

Objectives

The need for investigations of the economic conditions which would make undersea mining feasible for entrepreneuring firms prompted this study. Knowledge gained from investigations of this nature is important because it informs potential investors of the conditions under which ocean minerals can be considered as economically mineable resources. With this motivating idea in mind, the following set of objectives were outlined for this study.

(1) To identify the major economic and physical parameters which affect the economic system of an ocean mining venture.

(2) To develop an economic model based on the major physical and economic parameters identified through objective 1.

(3) To incorporate a measure of economic worth in the model which will measure the effects of varying parameter values.

(4) To test the model with data characteristic of a particular ocean mineral deposit and to measure the sensitivity of variables in the model.

(5) In the test case, to make conclusions about the values of parameters and their effects on the economic worth of a mining venture.

The main purpose of this paper is to determine the economic factors affecting the exploitation of undersea mineral deposits and to develop an economic model applicable to a wide range of undersea deposits. Exploitation in this context refers to the exploration for mineral deposits, the extraction of the ore, the beneficiation and processing of the ore, the transportation and marketing of the mineral products, and the disposal of waste products. The content of the paper will be basically restricted to ocean deposits which occur on the surface of the seafloor or are contained in the first layers of undersea sediment and rock. These are the most likely deposits for initial ocean mining ventures because they are the easiest to find and in some cases can be mined using various dredging techniques. Deposits of coal and iron ore which occur in veins in oceanic mountains or ridges are more difficult to locate and to exploit. At the present time this type of deposit is mined only from land based tunnels, as an ocean based system would require highly sophisticated equipment and methods.

Other deposits such as oil, gas, and sulfur are presently being mined in great quantity from the oceans. The offshore production of oil and natural gas alone approaches $4.5 billion per year in value (13). The recovery procedure for these minerals is very specialized, however, and will not be covered in this paper. The procedure involves drilling bore-holes through the ocean floor and pumping the mineral in a liquid or gaseous state to the surface. The drilling is usually done relatively near shore from ocean platforms. The trend, however, has been to drill further and further from land, and new techniques may have to be developed in the future.

The location of undersea deposits varies from nearshore beach and continental shelf deposits to deep sea deposits in depths exceeding 12,000 feet. The sources of these deposits also vary, but are thought to be generally dependent on the water cycle. As rain falls on land, it absorbs some of the mineral content of the earth and carries it into the sea. The dynamic forces of the sea then distribute the minerals according to some preferential pattern. The minerals may be transported by the movement of the ocean waters until a particular ocean environment causes them to precipitate. The result is a mineral deposit at a specific undersea location. One explanation for the existence of manganese and phosphate rock deposits, for example, is based on this precipitation concept. Another theory, however, is that the manganese nodules were formed from undersea volcanic eruptions. When more knowledge is gained about the ocean and about the formation of these mineral deposits, man may be able to relate the ocean conditions to the formation of specific mineral deposits and in this way narrow the search for minerals to particular regions.

Jurisdiction over ocean deposits has not yet been definitely established and legal rights will be one of the many factors pioneering undersea mining firms will have to consider. Pioneer firms will need some guarantee of exclusive mineral rights, otherwise they will be taking a risk that someone else will encroach on the system they have developed. This factor, along with many others, will be examined in the methodological order listed below. After the economic factors have been determined, an economic model will be developed and tested.

(1) Analysis of the various types of minerals which are known to exist in ocean deposits.

(2) Analysis of the environmental factors which will affect undersea mining operations.

(3) Analysis of the current technology in undersea mining.

(4) Determination of the economic factors related to undersea mining from their associated physical parameters.

(5) Development of a general economic model from the economic factors determined in step 4.

(6) Projections and conclusions about undersea mining from tests made using the economic model.

Minerals

Table 1 gives a listing of materials which could be won from the sea (15) and (18). Some of these materials are already being extracted from offshore deposits and the remainder are being considered for exploitation at this time. The most probable materials to be mined in the immediate future are:

(1) Manganese nodules containing manganese, nickel, copper and cobalt located in Pacific and Atlantic Ocean deposits;

(2) Red Sea sediments in the Deeps of the Red Sea which contain gold, silver, zinc and copper;

(3) Phosphorite nodules located off the coast of California.

Deepsea Ventures, a subsidiary of Tenneco Oil Company, has already tested a deep sea ocean mining system for the recovery of manganese nodules in the Pacific Ocean. The management of this firm plans to produce minerals from deposits in the Pacific by 1975. Preliminary research, design and testing of this ocean mining system has already cost Deepsea Ventures $20 million, and the company expects to spend a total of $200 million before the full scale mining system is complete (22).

Table 1. Materials of Interest from the Sea

Cement	Salt	Coal
Iron Ore	Potash	Oil
Copper	Platinum Metals	Gas
Lead	Fluorspar	Sulfur
Zinc	Magnesium Metal	Calcium Carbonate
Silver	Chromite	Monazite
Gold	Tungsten	Cassiterite
Gypsum	Mercury	Magnetite
Cobalt	Bromine	Molybdenum
Nickel	Columbium	Vanadium
Sand and Gravel	Tantalum	Clays
Diamonds	Rutile	Calcareous Oozes
Manganese Ore	Barite	Siliceous Oozes
Phosphate	Ilmenite	Strontium
Tin	Bismuth	Borax
Bauxite	Zircon	Scheelite
Uranium	Precious Coral	
Wolframite	Glauconite	

Environmental Factors

The type of mineral deposit and its geographic location determine many of the environmental factors which undersea mining firms, such as Deepsea Ventures, must face. The dynamics of ocean water, depth, distance from shore, weather, and the stability of the seafloor are only a few of these environmental factors. The mining system must be designed to operate under varying states of these factors. Since large capital investments of $200 million or more are involved in ocean mining systems, large quantities of production must be forthcoming to make the systems economically feasible. A maximum operating time is thus desired in most ocean systems. Innovative changes in equipment design can be made in some locations where environmental conditions prohibit the use of conventional techniques. For instance, waves and swells of 5 feet are generally considered a limiting condition for the operation of most conventional dredging and drilling techniques. Off the coast of Southwest Africa, where diamonds are presently being dredged from the seafloor with hydrulic dredges, wave conditions often exceed this 5-foot limiting height. In this case, new equipment capable of working in a 10-foot sea gives 250 per cent more dredging time than that limited to a 5-foot sea. The increased operating time permits higher utilizations of costly mining equipment and results in significant increases in production (8).

Hardware

The design of hardware for ocean mining operations is extremely important to the economic system of ocean mining, because the environmental conditions mentioned above can cause dramatic fluctuations in mineral production. If the hardware is not designed to operate under the environmental conditions of a particular ocean deposit location, the throughputs of minerals will probably be inadequate to justify the mining operation. The types of hardware which will be needed for typical ocean mining operations are:

(1) various types of exploration equipment such as core drills, samplers, undersea submersibles, survey vessels, magnetometers, and sample analysis equipment;

(2) extraction equipment such as bucket ladder dredges, draglines and clamshells, hydraulic dredges, air-lifts, hydrojet dredges, and various types of seafloor mining equipment;

(3) beneficiation facilities for washing, sizing, comminution, flotation, amalgamation, course gravity and magnetic separation;

(4) transportation equipment such as barges, ore carriers, pipelines, slurry ships, and possibly ore carrying submarines;

(5) accurate navigation and positioning equipment;

(6) processing facilities which will depend on the type of minerals and mineral compounds present in the extracted ore, as well as the cost of various processing techniques for a particular geographic location;

(7) other miscellaneous types of equipment such as helicopters to fly supplies and personnel to the mining operation, loading and unloading equipment for barges and ships, and storage facilities for the different stages of production.

Organization

The next three chapters of this paper analyze previous economic work, the minerals of the ocean, the available hardware for ocean mining, and the environmental conditions which exist at ocean mining sites.

Through these analyses certain basic economic factors are determined. Every mineral deposit will of course have economic charcteristic which are peculiar to the physical and economic environment in which the deposit exists. The purpose of the economic model which is developed in this paper is to group these economic characteristics into general categories or subsystems of the total economic system of ocean mining and to determine the basic interactions of the subsystems.

Incorporated within the economic model is a measure of economic worth to evaluate various ocean mining deposits. The rate of return technique, a generally accepted measure of economic worth for capital investments, is used. This technique will account for the differences in the time of receipts and expenditures in the cash flow of an ocean mining firm. The time value of money is an extremely important consideration in ocean mining activities because there may be as many as six years between the initial expenditures and the first revenues.

Table 2 shows a basic breakdown of the subsystems of the economic system as defined by this economic model. These subsystems can be thought of as cost or revenue generating parts of an ocean mining system. They are grouped according to the function they accomplish for the mining operation, but they should be considered as interacting parts of the whole system and not as individual functions. The interfaces between the various functions may be as important or more important than the optimization of the function itself. The mining subsystem must integrate smoothly with the transportation subsystem and the processing subsystem to efficiently produce a product. In addition, the product produced must be of a quality and cost to satisfy the marketing function. All of these parts are essential to the operation of the economic system.

Table 2. Economic Subsystems

Subsystem	Basic Components
Developmental	
	Exploration
	Design of Equipment
	Construction of Equipment
	Start Up
Finance	
	Interest
	Insurance
Mining and Beneficiation	
	Labor
	Operating Cost
	Overhead
Transportation	
	Labor
	Operating Cost
	Overhead
Processing	
	Raw Materials
	Labor
	Operating Cost
	Overhead

Table 2. Economic Subsystems (cont'd)

Marketing	
	Sales
	Overhead
Revenue	
	Price
	Production
	Demand

Table 2 gives the general format on which the economic model is based. A finer breakdown of the components of the subsystems is given in a later chapter, but the above structure is retained in the model. Most ocean mining systems will have a structure similar to this one. Some mineral deposits may omit or rearrange the subsystems, however. Sand and gravel deposits, for instance, may not require processing before they are marketed.

After the development of the economic model, a test is made of the model using data from Pacific Ocean manganese nodule deposits. These deposits have received considerable attention in the literature of the last few years, and previous studies have indicated that ocean manganese nodules may be economical to mine at this time (18). They were chosen for this test because of the relative abundance of available information concerning them.

The tests consist of varying one of the economic parameters of the model while the remaining parameters are held constant. The resultant changes in the measure of economic worth used in the model give indications of the importance of the tested economic paramater to the economic system. Included among the variables which were chosen for examination are:

(1) the production rate per year,

(2) the cost of the mining equipment,

(3) the number of years capital is borrowed,

(4) the market price for the minerals.

CHAPTER II

MINERALS OF INTEREST

Table 1 of Chapter I listed the ocean minerals which are considered to be of potential economic importance. Marine exploration activities have thus far found these minerals in a variety of locations and in several different types of deposits. Classified according to type of deposit they are: (1) minerals contained in seawater, (2) surficial and buried beach and placer deposits, (3) metal rich sediments in Red Sea Deeps, (4) surficial nodular or crust type deposits, (5) vein deposits in undersea rock, (6) seafloor clays and oozes, and (7) other deposits such as oil, sulfur, gas and salt (8) and (18).

Deposits of types (2), (3), (4), and (6) are the ones of prime interest in this study. Minerals contained in seawater are not covered because the typical recovery system for them does not necessarily have to be designed to cope with the dynamic forces of an ocean environment. Facilities for extracting minerals from seawater can be located on land and the adjacent ocean waters can serve as the ore body. This system does not require the extensive exploration activities or the ocean support systems that undersea mining operations require. Deposits of the vein type, such as coal or iron ore, on the other hand, require more technological development than do the surficial deposits. Locating these vein deposits and extracting the mineral ore is much more difficult, and therefore, they will probably lag behind surficial deposits in economic development. At the present time some of these vein deposits are mined through land based tunnels which extend under the ocean, however, there are no ocean based systems mining them. Other deposits of oil, gas, and sulfur are not emphasized in this study because the technique for their recovery is specialized and already well developed.

Beach and Placer Deposits

One of the easier types of deposits to mine are the nearshore beach and placer deposits containing minerals such as gold, platinum, diamonds, magnetitite, ilmentie, zircon, rutile, columbite, chromite, tin, cassiterite, scheelite, wolframite, monozite, quartz, calcium carbonate, and sand gravel (18). Gold has been reported off the coast of Alaska and Oregon in placer deposits of the continental shelf, but does not appear to be present in economically mineable quantities. Analyses of 82 samples collected from the surface of the continental shelf between the Oregon-California border and Eureka, California indicate that the background gold content of this shelf is about 0.1 ppb. Other tracts have gold values abouve 10 ppb and the richest sample contains 390 ppb. Based on a price of $35/oz. for gold, 10 ppb is equivalent to $0.01 per ton. At these values surface concentrations are not economical, but there may be higher concentrations located in buried placer deposits (21).

Several companies have applied for and received permits to explore the continental shelf off Nome, Alaska. These permits, however, may not reflect the actual interest in mining this area; because they can be obtained for only $20. Some of the companies which have applied for them are probably speculating on the chance that gold will be found in sufficient concentrations to mine (18) and (25).

Diamonds are currently being mined off the coast of Southwest Africa by the Marine Diamond Corporation. This company began operations in 1961 and has mined diamonds in waters up to 100 feet deep. Diamonds usually occur in concentrations of about one part diamond per 100 million parts of gangue material in these offshore areas, and therefore high throughputs of material are required for economic recovery. Marine Diamond Corporation's recovery system includes air-lift hydraulic dredges with throughputs of 13,380 and 25,200 cubic yards per month. In 1964-1965, 221,500 cubic yards of dredged material yielded $8.0 million worth of diamonds (9). Even with this high throughput, however, the Marine Diamond Corporation reported a loss of $2.02 per cubic yard of gravel in that year. Part of this loss was due to a storm in the area which wrecked one of the mining vessels. This points out the need to analyze the environmental conditions of the ocean and to prepare for the worst conditions which could be expected for a particular location.

The mining vessels used by Marine Diamond Corporation are combined air-lift and suction dredging equipment installed on converted pipe laying barges. The diamonds are recovered from the dredged material aboard the mining vessel through the use of a system to separate the diamonds from the gangue material. The final concentrate from the recovery process is hand-sorted to remove the diamonds. Tests run on the system indicate that it is almost 100 per cent efficient in the recovery of diamonds between 1.5 mm in diameter to 1 inch in diameter (17).

Magnetite, or iron sand, is another mineral found in nearshore beach deposits. In most cases magnetite is found in concentrations too low to warrant recovery systems. However, in Ariake Bay, Japan, 40 million tons of refineable iron ore reserves have been reported in a 31 square mile area. These sands are presently being mined with grab-bucket dredges at a reported production rate of 30,000 tons per month. According to John L. Mero the cost of dredging and concentrating the sands is approximately $5 per ton of concentrate. The deposits assay at 56 per cent iron and 5 per cent of the dredged material is recoverable iron ore (18). In 1962 there were three offshore mining operations for recovering iron sands in Japan. These operations yielded 36,000 tons of iron ore at a value of $3.6 million (9).

One of the less glamerous but more profitable minerals obtained from beach deposits is sand and gravel. In 1966 there were 38 mining operations dredging sand and gravel in the United States and Great Britain. The operations produced 100 million cubic yards of material at a value of approximately $100 million (9). Sand and gravel is used for beach filling, in roads, or other construction filling functions. It is dredged from undersea deposits with hydraulic dredges and normally requires no processing. Offshore world production of this material in 1967-1968 was estimated to be $150 million (16).

Explorations of beach deposits off the coast of Australia have resulted in the discovery of heavy mineral deposits of zircon, rutile, and ilmenite. Planet Metals Ltd. of Sidney, Australia, has been exploring this area of approximately 3,777 square miles since the mid 1960's and has plans to mine the heavy minerals. The company has not published the economic factors of recovery, but it is believed that there are several areas which have high potential. The heavy minerals have thus far been found in two types of deposits: (1) blanket type of deposits of 5 to 15 foot depth and in some cases 1 per cent heavy mineral content, and (2) narrow seams of minerals and sand 400 to 1000 feet wide, 10 to 15 feet thick, and buried beneath 10 or 15 feet of barren sand. The longest seam discovered is 16,000 feet long and contains greater than 1 per cent heavy mineral content (4).

In placer deposits off the coast of Thailand and Indonesia, tin is mined with ladder-bucket dredges. The deposits are located in water 60-100 feet deep. In 1965 offshore mining of tin produced 10,000 tons of concentrates at a value of $24.2 million (9). Although a relatively low priced mineral, tin can be recovered from ocean deposits with a substantial profit for the mining firm.

Red Sea Deposits

Estimates of the value of heavy metals in the Atlantis II Deep of the Red Sea have been $1.5 billion, $2.5 billion, and $8 billion (12). The variations in these estimates is due to uncertain factors related to the deposits. Unfortunately, the data from observations of this deep and others in the Red Sea have not been coordinated to give a definite picture of the deeps. Uncertainty exists about the thickness of the sediment layer, the variation in composition between different parts of the deep, and many other physical factors. The $2.5 billion estimate mentioned above was based on a deposit thickness of 10 meters, or 50 million tons of brine-free sediment. The $8 billion estimate was based on a deposit thickness fo 20 to 30 meters. This discrepancy may be cleared up when more detailed information is available concerning the deeps. In 1969 a Sudanese-American-German group began further study of this area, but for competitive reasons their data will probably not be published for some years.

The facts that are known about Atlantis II Deep indicate that further study is worthwhile. The deep is approximately 16 square miles in area and contains minerals such as zinc, copper, lead, gold and silver. The minerals are located under 6000 feet of water in a brine rich sediment. The average assay of the metals in the deep are: Fe, 29 per cent; Zn, 3.4 per cent; Cu, 1.3 per cent; Pb, 0.1 per cent; Ag, 54 ppm; and Au, 0.5 ppm. One of the problems which have been mentioned regarding the mining of these minerals is the disposal of waste material. The nearest land is 60 miles from the deposit, and any waste disposed of in the water will merely drift back into the deposit and contaminate it.

Nodular Deposits

Two of the deposits which have received the most attention in economical analyses of ocean mining ventures have been the manganese nodule deposits of the Pacific Ocean and the phosphate rock deposits off the coast of California. The surficial nature of these deposits kindles part of this interest, because there is no overburden to remove to get to the minerals. It is believed that hydraulic or dragline dredges will be able to skim the first layer of seafloor sediment and recover the mineralized rocks. Also kindling interest is the wide area in which these rocks have been found. Mero reports observations of manganese nodules in several regions of the Pacific Ocean. He estimates that there are 1.7 trillion tons of manganese nodules in the Pacific (18).

Manganese nodules which have been recovered in samples generally range in size between 0.5 and 25 cm in diameter. Their average assay is estimated to be 24.2 per cent manganese, 14.0 per cent iron, 1.0 per cent nickel, 0.35 per cent cobalt and 0.53 per cent copper (18). Variations in the composition of the nodules has been reported and seems to be related to the region in which the nodules are located. The cause of this variation in assay could be the preferential precipitation of certain minerals under particular environmental conditions. Mero has divided the Pacific Ocean nodule sites into four regions according to the chemical composition of the nodules which have been recovered from each region. The first region lies generally along the continents and is high in nodule iron content. The second region is located near the west coasts of North and South America and has high nodule manganese content. The third and fourth regions are in the central part of the Pacific and are relatively more wealthy in nickel, copper and cobalt. The significance of these regions is magnified when changes in the demand for particular metals occur in the market place. A mining firm might be able to relocate its mining vessels in different regions depending on the market conditions. This would reduce some of the risk involved in this high capital endeavour by giving the firm alternative quantities of production for specific minerals. Since the nodules contain several minerals, production from one location may result in an oversupply of some of the minerals when the demand for others is met. By choosing a location with the proper mineral composition for the nodules, this effect may be reduced.

The most probable sites for initial manganese nodule production are some 4000 nautical miles from the California coast in the mid-Pacific. They are located in the depths of from 12,000 to 18,000 feet and assay: 26 to 27 per cent manganese, 1.3 per cent nickel, 1.0 per cent copper, and 0.2 per cent cobalt (6). One of the pioneer firms in ocean mining, Deepsea Ventures, has plans to be in full scale production of processed metals from ocean manganese nodules by 1975-76. Deepsea Ventures has already tested a manganese nodule recovery and processing system in shallow water off the Georgia coast, and is now proceeding with plans to mine nodules in the Pacific.

The phosphorite nodules which had been found in ocean deposits up until 1964 averaged 2 inches in diameter and contained 20 - 30 per cent P_2O_5. Some of the more interesting deposits occur off the coast of California in water depths of 190 to 600 feet (25). Four areas that have been sampled and are receiving attention are: (1) the Thirty-Mile Bank (west of San Diego); (2) the Forty-Mile Bank (west of San Diego); (3) an area 10 miles off Santa Monica Bay; and (4) several zones of lesser interest 60 to 80 miles northwest and southwest of San Francisco (25). The P_2O_5 content of samples from these four areas range from 22.4 per cent in the Thirty-Mile Bank to 29.6 per cent in the Forty-Mile Bank (18). The bulk of marketed phosphate rock from land sources ranges in grade between 31-36 per cent P_2O_5. These ocean deposits will, therefore, have to be upgraded to a minimum P_2O_5 content of 31 per cent before they will be marketable.

Some authorities believe that due to impurities in the ocean deposits, a substantial processing cost will have to be born by the ocean phosphate. This could reduce the economics of mining phosphate from an ocean environment. One of the main advantages that ocean mining of phosphate generates is a reduction in transportation costs to areas which have no native land deposits of phosphate. California, for example, must acquire the phosphate it needs from Florida or other smaller mines within the United States. For marine phosphate to be competitive with land mined phosphate, it must offset the additional cost of mining and processing with the reduction in transportation costs.

Seafloor Clays and Oozes

Pelagic sediments are oceanic materials that are located in deep water some distance from land. Those pelagic sediments which cnntain less than 30 per cent of organic remains are called red clay, while those with more than 30 per cent of organic remains are designated as oozes (18). The oozes are further categorized according to the type of organism whose remains constitute much of the material in the ooze. Table 3 shows how these oozes are categorized and lists some of their potential uses. The reserves of these oozes under the sea are fantastically large, but so are the land reserves of the materials for which they might substitute. Calcareous oozes alone cover about 36 per cent of the ocean floor, and it is estimated, using an average thickness of 400 meters, that there are 10^{16} tons of calcareous oozes in the oceans. Reserves of siliceous oozes on the seafloor are estimated to be 10^{13} tons (18).

Table 3. Oceanic Oozes

Major Group	Subgroup	Constituent	Use
Calcareous Ooze		skeletal remains of plankton animals & plants	
	Globigerina Ooze	tests of pelagic Foraminifera	substitute for lime- stone in cement

Table 3. Oceanic Oozes (cont'd)

Major Group	Subgroup	Constituent	Use
	Pteropod Ooze	shells of pelagic molluscs	
	Coccolith Ooze	remains of an Algae called Coccolithophoridae	
Siliceous Ooze		remains of plankton animals and plants	
	Diatom Ooze	diatom frustules from plankton plants	light-weight aggregates for concrete, a filter, in insulation bricks, and mineral filler.
	Radiolarian Ooze	radiolarian skeletans of plankton animals	

The oozes of the ocean may not be mined anytime in the near future, but like many other ocean deposits they can affect the price of land mined materials. If the price of minerals from land mines rises too high, these ocean minerals may be turned to as substitutes. The technology is available to recover the oozes from the seafloor, and all that is lacking is the economic incentive to do so. Mero suggests that a hydraulic dredge would be best for mining the oozes from depths of 4000 meters. He estimates that for $15 million a dredge could be designed and built to pump about 25,000 tons of ooze per day (18).

Red clay, another pelagic sediment, is formed by the settling of particles of igneous rocks carried by the ocean waters. The particles enter the ocean through rivers and streams and come to rest on the ocean floor. Like the oceanic oozes, red clay occupies a large portion of the seafloor. Reserves are estimated to be near 10^{16} tons in all the oceans.

The mineral content of red clay has not encouraged any economic interest, but the material may be used in the manufacture of clay products. At present no companies have reported plans to mine the clay from the ocean, and many other minerals will probably be mined before any attention is given to the red clay.

CHAPTER III

PREVIOUS ECONOMIC RESEARCH

Although there have been numerous articles written about the resources of the sea and the potential that these resources have for serving mankind, there have only been a few articles written on the economics of ocean mineral recovery. The reason for this lack of attention to the economic aspects of undersea mining is due in part to the incomplete information which is available on specific mineral deposits. This lack of information makes accurate economic analysis very difficult and increases the risk of reaching the wrong conclusions. It is imperative that extensive studies be conducted at a mining site before major capital expenditures are expended. The economic studies that have been reported to this date have concentrated mainly on a few deposits such as the manganese nodule deposits of the Pacific and the phosphate rock deposits off the coast of California. They have mainly been directed at determining whether a particular mineral is economical or uneconomical to mine. The results of the economic analyses have been both optimistic and pessimistic as to the potential profit which could be expected by pioneering mining firms.

The direction of this study is oriented more toward a general overall view of the economic system that will be associated with ocean mining ventures. Although manganese nodule deposits are used in the tests of the economic model developed in this study, the major emphasis is on the economic system and its important parameters instead of on the individual deposit. The tests that are made of the model are aimed at determining the effect of such parameters as the market prices of the minerals and the annual production rate.

One of the main economic analyses which have been conducted on ocean mineral recovery was performed by John L. Mero and is reported in his book, The Mineral Resources of the Sea. This book was originally published in 1964 and has received considerable attention since that time. Major emphasis in the book is given to the manganese nodule deposits of the Pacific Ocean. Mero suggested two major systems for mining the manganese nodules from depths of 10,000 feet and estimated the cost of both systems (18).

Using a deep sea drag dredge to extract the nodules, Mero estimated production costs of $12.10 per ton of dredged nodules in 1000 feet of water to $30.60 per ton in 10,000 feet of water. Using a deep sea hydraulic dredge he estimates production costs of $2.29 and $4.95 for these same dredging depths. In a later article published in 1968 in Chemical Engineering, Mero reports estimated annual after-tax returns of about 107 per cent for a manganese nodule recovery system. The expected cost of this system which produces nodules at a rate of 5000 tons/day is given as $85 million, including $60 million for a processing facility, $5 million for the dredge, $5 million in preliminary studies and start up costs, and $15 million in operating capital (17).

In all of his articles, Mero has been extremely optimistic about the economic potential of undersea mineral deposits. His book, The Mineral Resources of the Sea, covers many of the technological, economic, and legal aspects of ocean mining and gives a bright picture for mining in the near future. Other authors, however, are not as optimistic. Philip E. Sorensen and Walter J. Mead, who have published economic studies on manganese nodules and phosphate rock deposits, believe that the pioneering ocean mining firm recovering manganese nodules faces prospective capital losses of around $122 million or more.

In 1968 Sorensen and Mead published an article in the American Journal of Agricultural Economics entitled "A Cost-Benefit Analysis of Ocean Mineral Resource Development: The Case of Manganese Nodules". In this analysis they segregated three parts of the overall mining system: dredging, transportation, and processing; and estimated the costs which would be incurred by each. A dredge for extracting 5,000 tons of nodules per day is expected by Sorensen and Mead to require a capital investment of approximately $150 million and yearly operating costs are estimated at $16.5 million. Transportation for the dredged material is delegated to a fleet of 18 barges and 16 ocean going tugs. The cost of the barges, which have an ore capacity of 10,000 short tons, is estimated at $550,000 each. The tugs are included at a charter rate of $1500 per day for each tug. The total transportation cost for the manganese nodules, including a $5 million port facility, is expected to be $15 million for equipment and $10.5 million per year for operating costs. The processing facility for 5000 tons of nodules per day is placed at $50 million and processing costs of $25-30/per ton are anticipated (23).

After Sorensen and Mead estimated costs for these three parts of the economic system of manganese nodule production, they discounted the costs and revenues at 6 per cent to their present value. Assuming no changes in prices they calculated present values of net operating revenue of $99 million and of capital cost of $175 million.

Some of the chief differences between Mero's analysis and that of Sorensen and Mead lie in the capital cost of the dredge and the processing cost. Mero believes that the processing cost could fall as low as $5 per ton, while Sorensen and Mead use an estimate of $25 per ton. The differences in the cost of the dredge ($5 million estimated by Mero; $150 million estimate by Sorensen and Mead) also causes considerable variation in the analyses. The prototype tests which have been run by Deepsea Ventures, Inc. may help solve some of the wide variation in these costs. If the processing facility which Deepsea Ventures tested can maintain the reported 95 per cent recovery rates (6) of minerals when full production is obtained, they may obtain lower processing costs than the $25 suggested by Sorensen and Mead. Sorensen and Mead based their estimate on recovery percentages of 85 per cent for Mn, 90 per cent for Co, 95 per cent for Ni, and 20 per cent for Cu.

Others who have written articles on the economics of manganese nodule production are David B. Brooks, H. D. Hess, and Alvin Kaufman. Brooks believes that manganese nodules are the best alternative resource for manganese that is available. He defines a resource as "a material that may or may not be exploitable at today's technology and today's prices, but that is sufficiently close to exploitability that it exerts some influence on price." Brooks feels that the capital investment required for initial ventures into manganese nodule production will be around $100 million. He sets a minimum economic production rate of 2000 tons per day (3).

Hess reports estimated after tax returns of 30-40 per cent for a 5000 ton per day operation. His analysis includes costs which are closely aligned with those of Mero (11). Kaufman takes a different approach from Hess and other authors. In an article written for the MTS Journal entitled "A Survey of the Economics of Ocean Mining", Kaufman gives a range of costs for ten different parts of the mining system. The range of total costs reported was from \$28.40 per ton to \$53.20 per ton. The range of revenues varied from \$5.50 per ton to \$130.40 per ton, with an average of \$43.60. Kaufman's analysis, however, was based on outputs of 1 million tons of nodules per year and water depths of 1000 feet. Most indications seem to point towards operating depths of 12,000 to 18,000 feet for initial nodule mining. The cost at these depths could be considerably larger than dredging at 1000 feet.

Kaufman, Hess, Sorensen and Mead, have also written articles on the mining of phosphorite nodules. Kaufman reports ranges in estimated phosphate mining costs from a low of \$12.00 per ton to a high of \$31.80 per ton. The range of revenues reported is \$12.00 to \$16.00 with an average of \$14 per ton. (Assumes output of 200,000 tons of nodules per year and water depth of 600 feet). Kaufman also mentions the work of M. P. Overall, who estimated the cost of a phosphate mining system using a drag dredging method to produce 400,000 tons per year. Overall estimated capital costs of \$3.5 million for the dredge and \$1.8 million per year in operating costs. Total mining cost was estimated at \$4.50 per ton. Using an hydraulic dredge total mining cost was computed at \$4.52 per ton.

Sorensen and Mead were more pessimistic about the costs of mining phosphate from deposits off the coast of California. In an article written for the Marine Technology Conference of 1970 entitled "A New

Economic Appraisal of Marine Phosphorite Deposits Off the California Coast", Sorensen and Mead estimate total mining costs to be between $15 and $22 per ton. In their opinion California marine phosphate deposits are not economical to mine and probably won't be in this century (24).

Hess reports mining costs of $5 to $7 per ton and a capital investment of $3.5 million. Estimated annual returns after taxes are computed at 30-40 per cent. This is one of the more optimistic reports on California phosphate deposits (11).

CHAPTER IV

ENVIRONMENTAL FACTORS AND AVAILABLE HARDWARE

Environmental Factors

Perhaps the major obstacle to the economical exploitation of many undersea mineral deposits is the construction of mining equipment which can operate for extended periods of time in an ocean environment. Waves, swells, currents, and other ocean phenomena can restrict the production time of any undersea mining system by creating movements or forces which render the equipment inoperable. In order to overcome these forces of nature, specially designed mining vessels and recovery systems are needed. One of the jobs of pioneer ocean mining firms will be to design and test various types of equipment. Under some ocean environmental conditions it may be found that a surface mining vessel is the best economical choice. Other conditions may favor semi-submerged, submerged, or seafloor mining vessels. Whatever the choice of equipment for the mining system, it should be economically feasible for operation in the environment in which the deposit exists.

Knowledge about many of the environmental conditions of ocean mineral deposits is severely lacking, and pioneer ocean mining firms may have to conduct considerable research at deposit sites to determine the design criteria for mining equipment. Some of these conditions may prove to be beneficial, while others may require more expensive designs. Phenomena such as the temperature differential between different depths in the ocean, the tides, or the currents, may be used as sources of energy.

Other phenomena such as salt water corrosion and seafloor instability may require special metals and excavating equipment. The knowledge undersea mining firms gain from research activities, although costly, may prove to be one of their greater assets. This knowledge could place them in an advantageous position to develop many other resources in the ocean.

Table 4 contains a list of many of the environmental factors that could affect the exploitation of undersea mineral deposits (5). These factors are categorized according to the medium or medium interface in which they occur. The mean and variation of the physical values that measure these factors should be determined and considered in the design of mining equipment. In the case of winds, for instance, the mean velocity and variation in wind speed could be important in the design of the superstructure of a surface mining vessel. Especially important might be the maximum wind speed that could be expected for a given location.

Air

The environmental conditions of the atmosphere above the ocean will affect that part of the ocean mining system which projects above the surface of the water. Equipment types which are most likely to be exposed to this environment are the superstructures of the mining and transportation vessels, the beneficiating plant, and the processing facility. The design of this equipment should be made to minimize the ill effects of varying atmospheric conditions. Winds, storms, poor visibility and other environmental conditions can cause losses in efficiency or completely curtail mining operations during certain parts of the year.

Table 4. Ocean Environmental Factors

<u>Air</u>	
Winds	
Hurricanes, gales and other storms	
Rain, snow, sleet and etc.	
Fog and other conditions of poor visibility	
Temperature	
<u>Air-Sea Interface</u>	
Waves and swells	Frictional effects
Currents	Salt water corrosion
Tides	Movement of masses on the ocean
Icing Conditions	
Stability of vessels and equipment	Sea level
<u>Sea</u>	
Depth	Visibility
Temperature	Acoustical properties
Pressure	Buoyancy
Currents	Tsunamis
Salt water corrosion	Frictional effects
Marine life	Distance from land
<u>Sea-Seafloor Interface</u>	
Turbidity currents	Visibility
Seafloor currents	Temperature
Marine life	Pressure

Table 4. Ocean Environmental Factors (cont'd)

Topography	Obstacles on seafloor
Slope	
<u>Seafloor</u>	
Topography	Earthquakes
Type of sediment	Depth of sediment
Shear strength and bearing strength	Area of mineral deposit
Slope stability	Abrasiveness of rock or sediment
Marine life	
Concentrations of minerals in deposit	Mineral compounds present
Depth of deposit in sediments	
Chemical corrosion	
Type of deposit	
Sediment drifts	
Source of deposit and sediment	

Equipment that is designed to operate during some of the poor conditions may be worth additional capital expenditures. High throughputs of material are necessary to justify the large capital investments required for undersea mining. Therefore, equipment which offers a greater number of operating days per year at the same production rate is more valuable than less efficient equipment, (assuming that there is a demand for the extra production).

Probably the two most important effects that winds and storms have on mining and transportation vessels are losses in maneuverability and stability. In the extreme case a vessel could be wrecked in high winds or gales. This could result in the loss of life and valuable equipment. A more common case would be the loss of operating time or increases in transport time. Steps can be taken, however, to minimize these effects. Ocean mining firms can study the past distributions of atmospheric conditions for a particular area to get an idea of what to expect in the future. Equipment and procedures can then be designed to counteract extreme environmental conditions and provide more operating time.

Air-Sea Interface

One of the more critical segments of the ocean environment occurs at the air-sea interface. Equipment operating at this interface must be capable of withstanding many severe dynamic forces. Waves, swells, currents, salt water corrosion, and etc. can cause damage to equipment which is not designed to accept the forces they produce.

In Southeast Asia, where tin is mined from offshore deposits, waves and swells in excess of 5 feet occur during approximately 30 per cent of the year. In Southwestern Africa, the site of offshore diamond mining, these conditions exist approximately 75 per cent of the time (8).

In areas which have extremely cold climates, icing conditions may restrict the operation of surface equipment. Deposits located off the coast of Alaska, for instance, may be blocked from the surface by layers of ice during part of the year. Mining systems based on surface vessels would most likely have to curtail operations during this part of the year. In this situation the icing conditions greatly affect the economics of mineral exploitation.

Sea

The sea contains many environmental factors which are strange to man. Many of these factors are not yet known or understood by him. The operation of mining equipment in this medium will, therefore, be on somewhat of an experimental nature. Tests may have to be run on much of the equipment before it is put into actual use.

Ocean depths that mining firms will encounter depend on the location of the mineral deposits they seek to exploit. Some deposits occur in waters 150 feet or less in depth. These are mainly beach or placer deposits of continental shelves. Other mineral deposits, such as manganese nodules, have been found in depths of 20,000 feet or more. The main effect that depth has, other than the associated conditions of temperature and pressure, is an increase in the distance between surface mining equipment and the mineral deposit. For seafloor based mining operations, the effect will be the greater distances that supplies, oxygen, and power will have to be moved through water.

The effects of pressure in the ocean environment will be most important at the greater depths. Since the pressure increases with depth, equipment operating at certain depths will have to be constructed to withstand these forces. If manned seafloor mining systems are established, equipment will have to be designed to house the crew, provide life support systems, and protect them from the outside pressure.

Salt water corrosion and marine life boring should be factors in determining the type of material that is used to build the equipment exposed to the sea. Tests have shown that certain materials are more susceptible to these conditions than are others. Certain alloys of nickel have been tested and good results have been reported. Other materials such as cast iron deteriorate rapidly in a marine environment.

Currents, tsunamis, and frictional forces can act to cause stresses in equipment extending from the surface to the seafloor deposit. The extension of this mining equipment has been likened to the suspension of a drinking straw from the top of the Empire State Building to the street below. A structure of this nature requires special designs to withstand the forces acting on it. Tsunamis, or giant waves caused by seafloor disturbances, might be given special consideration due to the sudden extreme forces caused by it.

Sea-Seafloor Interface

At the interface between the waters of the ocean and the sediment of the seafloor, design problems center on the type of equipment used to extract minerals and or sediment from the deposit. Where visibility is necessary to align excavating equipment with the deposit, underwater television cameras may be used. These cameras will be useless unless the excavating equipment can be designed so that it does not stir up the seafloor sediment and impair visibility. Turbidity currents will have the same effect, as they too impair visibility.

The slope of the deposit, the topography of the area, and obstacles on the seafloor also affect the design of excavating equipment. If the extraction method is to skim the top layer of sediment off the seafloor, the excavating equipment should be designed to avoid or move obstructions on the ocean floor and to follow the contours of the floor. One of the problems which the Marine Diamond Corporation has in mining diamond deposits off Southwest Africa is the irregularity of the seafloor at the deposits. Trenches and gullies in the area offer cracks in which diamonds become lodged and are difficult to extract. The design of the excavating equipment which comes in contact with the deposit in this case, affects the efficiency of the mining operation and the economic justification of the mining venture.

Seafloor

Many of the environmental conditions of the seafloor correspond to conditions present at land mining sites. Shear strength and bearing strength of sediment are important in determining the weight of equipment resting on the seafloor. Some mineral extraction systems have been proposed which involve the operation of tractor type vehicles on the sediment. The feasibility of these systems will depend to a large extent on the support that the sediment gives to the equipment.

Of prime economic importance to any undersea deposit are the concentrations of minerals in the deposits. Most authorities believe that ocean mining systems will cost more than comparable land mining systems. To be economical, therefore, ocean deposits must have higher concentrations of minerals or must be able to attain higher throughputs of material.

Not only are the concentrations of minerals important, but so are the mineral compounds present in the deposit. Processing costs can be a major economical factor in the mining system and are greatly affected by the type of compound. Some authorities, for instance, believe that phosphate rock from ocean deposits off California will require \$2 to \$5 per ton to process instead of \$1 to \$2 per ton because of a high percentage of calcium carbonate in the rock (24).

Hardware

An excellent survey of the equipment that is available for ocean mining was published in the Marine Technology Society Journal of 1966. The survey was entitled, "A Review of Available Hardware Needed for Undersea Mining" and was written by C. G. Welling and M. J. Cruickshank (10). The equipment listed in this article emphasizes the exploration and extraction phases of the mining systems. Not only are the types of equipment listed, but also the manufacturer of the equipment, some important operating specifications, and the general usage of the equipment. In a shorter article presented in the Engineering and Mining Journal of January, 1968, M. J. Cruickshank, C. M. Romanowitz, and M. P. Overall cover some of the basic components of ocean mining hardware (9). This article entitled, "Offshore Mining - Present and Future", emphasizes the components of the excavation equipment. Several designs for equipment that extract sediment from the seafloor, lift sediment to surface, or support mining equipment are sketched and presented in Figures 7, 8 and 9 of this article (9). Almost all of the present excavating systems for ocean deposits consist of a combination of the equipment sketched in these figures. The particular combination used for a deposit depends on the environmental conditions at the location of the deposit.

A more recent paper written for the April, 1971 issue of Marine Technology by Raymond Kaufman reports four new concepts for undersea mining (14). Three of these concepts were patented in 1969 and the fourth was patented in 1966. The nature of these concepts is generally that of a submerged vehicle that collects the minerals and sediment from the seafloor and then pumps them through a pipe to a surface vessel. Cruickshank, Romanowitz, and Overall believe that there will be a trend toward this type of arrangement as the depth of the deposits increase (9).

Listed in Table 5 are the physical activities associated with ocean mining systems and some of the equipment corresponding to each activity (9). The type of equipment which is chosen for the mining of a particular deposit should be based on the environmental factors of Table 3, the specifications of the equipment, and the cost of the equipment. The physical activities are listed under headings which group them according to the functional part of the mining system to which they belong. The functional parts include: (1) exploration, (2) extraction of ore, (3) beneficiation, (4) transportation, and (5) processing.

Table 5. Types of Hardware Needed for Undersea Mining

Function	Equipment	Characteristics
Exploration		
Transportation to sample sites	Oceanographic Ships	Size, speed, cost range and etc.
Ship Operation	Navigation Systems (Loran, Lorac and Decca)	Range, accuracy, cost and area coverage
Survey	Depth recorders, sub-bottom profilers and magnetometers	Accuracy, power, and sediment penetration
Sampling	Corers, drills, grab buckets, television cameras	Depth, power, cost, penetration and recovery
Sample Analysis	Wet chemistry, x-ray diffraction, flotation and grinding	Reliability, accuracy, ease of use and separating ability
Extraction		

Table 5. Types of Hardware Needed for Undersea Mining (cont'd)

Function	Equipment	Characteristics
Sediment movement	Dipper, dragline, clamshell, bucket ladder, rotary cutter, bucket wheel, hydro-jet and suction	Capacity, power, negotiation of obstacles, cutting and digging ability
Sediment lifting	Bucket line, conveyor, suction pump, airlift and jetlift	Depth, capacity, power, volume moved per unit time and cost
Support and Control	Barge hull, ship hull, popoffka, catamaran, semi-subplatform, submarine, platform, and bottom vehicles	Stability, cost, maneuverability, space, storage capacity and speed
Beneficiation	Crushing, grinding, gravity and magnetic separators	Efficiency, power, cost production, space requirements and per cent recovery
Transportation	Barges, ships, tugs, helicopters, and submarines	Speed, power, cost, capacity, operating crew and cost of loading and unloading
Processing	Building, tanks, furnaces, lab equipment and etc.	Percent recovery, cost, production rate, quality and waste disposal

CHAPTER V

DESIGN OF THE ECONOMIC MODEL

The design of an economic model for undersea mining is necessarily general in form because of the variation in the environmental factors of different ocean deposits. Even though these factors cause economic conditions that are peculiar to a particular deposit, there are several basic economic subsystems which are common to a wide variety of undersea deposits. By combining these subsystems into an overall model, a tool can be developed that will aid in the analysis of many ocean deposits.

As is the case with most models, certain assumptions have to be made about actual systems in order to facilitate the use of the model. The following list of assumptions have been made in the development of this model.

Assumptions

1. The following quantities are assumed constant over the analysis period:

    a. the price of each mineral recovered from the ocean deposit

    b. the costs per year of the mining operation after the developmental stage

    c. mining production per year after the developmental stage

    d. the concentration of each mineral in the deposit

    e. the per cent recovery of the processing facility for each mineral

2. All minerals produced from the undersea ore can be sold at

the constant price levels inputed by the analyst.

3. The internal rate of return measure of economic worth is an acceptable technique for demonstrating the effects caused by changes in the values of economic variables in the model.

4. The seven economic subsystems which form the general model encompass all the major cost and revenue generating parts of an ocean mining system.

Measures of Economic Worth

The economic measures designed for use with this model are the rate of returns on ownership and on total investment. Ownership in this context refers to monies directly inputed by the mining firm, while total investment includes ownership, long term debt and short term debt. These measures are included in the model for the purposes of demonstrating the effects of different sets of economic conditions and of illustrating the general worth of an ocean mining investment.

Both measures are calculated through the use of a trial and error routine. This routine searches for the interest rate which equates the present worths of the costs and returns. In the case of the rate of return on ownership, RO, the costs are the ownership payments in each year and the returns are the profits made in that year. A measure of this nature gives the mining firm an indication of the rate of return it could expect on the capital it invests. For the second measure, the rate of return on total investment, RI, the costs include the ownership payments through a particular year, the long term loans outstanding, and the short term loans outstanding for that year. The returns include both the profits generated through a particular year and the value of the physical assets owned by the mining firm.

Equation 1 is the single payment present worth formula which is used to discount the costs and returns of the investment. In the application of this formula, it is assumed that all receipts and disbursements occur at the end of an interest period. In this analysis an interest period will be equivalent to a year, therefore, receipts and disbursements are assumed to occur at the end of each year.

Equation 1 - Single Payment Present Worth Factor (1)

$$SPPW(i,n) = 1/(1 + i)^n$$

where: i = interest rate

n = number of periods after time zero

time zero = the time set by the analyzer as the present time of the study.

The present worth formula is used to discount the value of money which is spread over more than one interest period. This procedure is important to an investment of this type because the cash receipts and disbursements occur in many different years. Since a dollar owned in the first year could be earning interest during the life of the investment, it is worth more than a dollar owned in a later year. The values for the rate of returns of this model thus indicate the interest rates per interest period that are earned by dollars invested in an ocean mining project.

Economic Model

The seven subsystems which form the basis of this model are pictured in Figure 1. Listed under each subsystem are some of the key cost factors

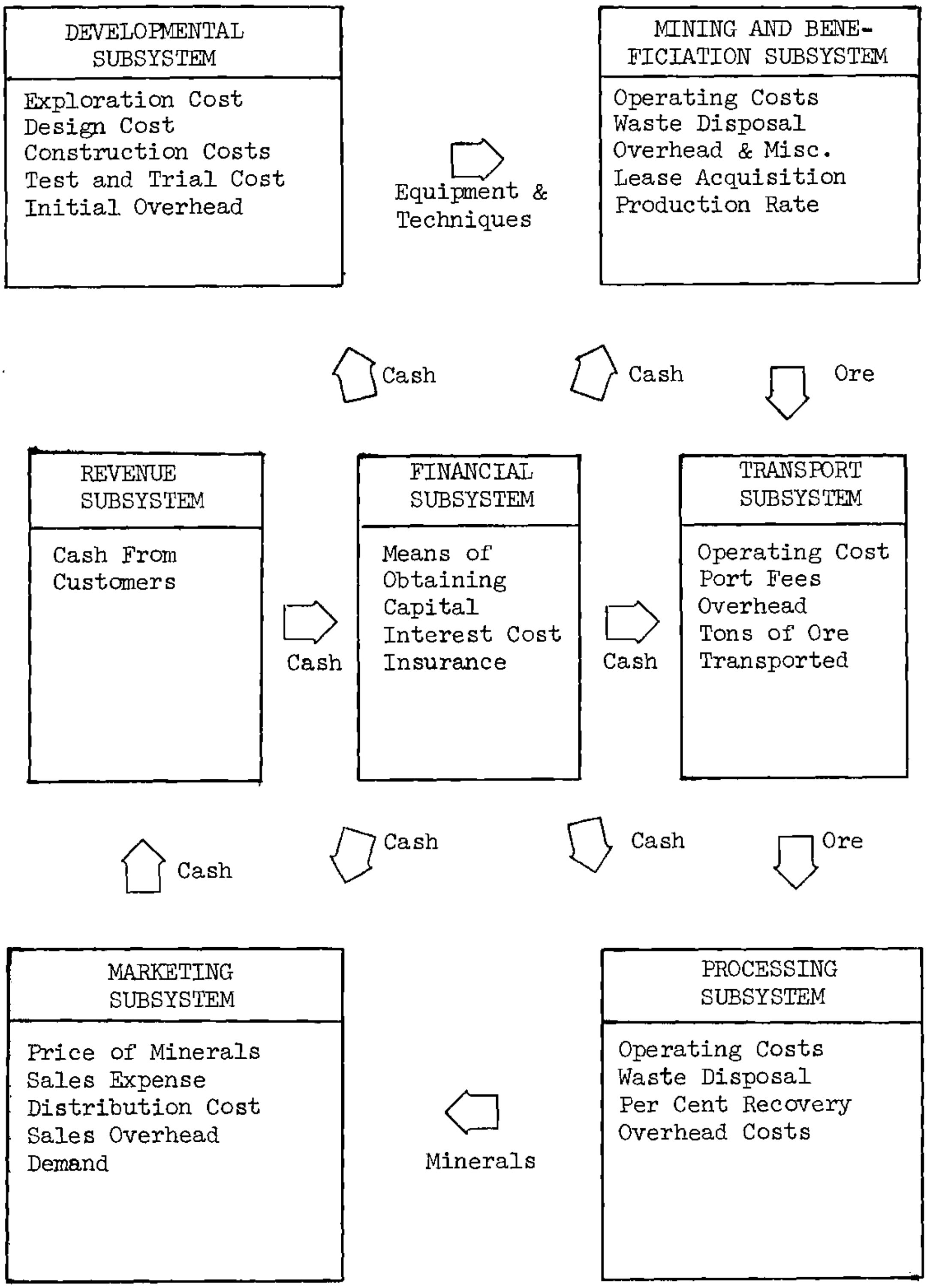

Figure 1. Economic System

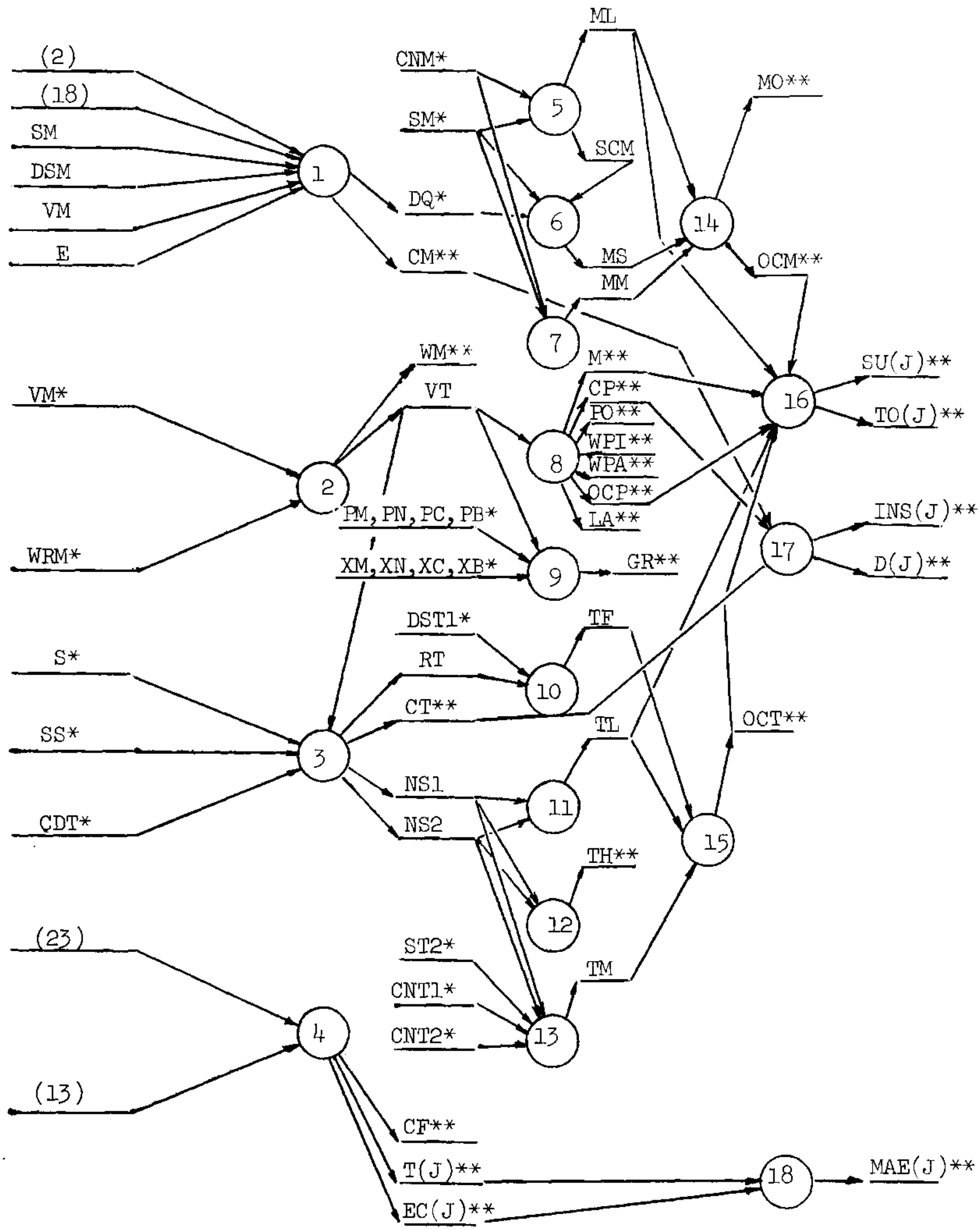

Figure 2. Cost Estimation

generated by the subsystem. The arrows which connect individual subsystems represent the general flows of material, knowledge and monies between the various functional parts of an ocean mining system.

The economic model which is developed in this chapter is divided into two phases. The first phase is concerned with estimating the cost factors of the seven general subsystems mentioned above. Once these values have been estimated for each year in the analysis period, they can be inputed into the second, or economic analysis, phase.

The cost estimation phase of the model is highly dependent on the type of ocean deposit being considered and on the type of equipment which is selected for that ocean deposit. Figure 2 shows this phase of the model for the special case of Pacific Ocean manganese nodule deposits. The mining system for which this analysis applies is an hydraulic dredging system. The transport equipment is the common ocean going barge-tug unit. In Figure 2 the input values that are needed for the cost estimating formulas are noted with one asterisk; while the estimated cost values, the inputs for phase two, are noted with two asterisks.

The cost of the hydraulic dredge is the only cost factor which is not programmed into the computer model. There are two reasons why this factor is hand calculated. The first reason is that the cost of the mining vessel is one of the factors selected for experimentation. It was selected because there has been a wide range of cost estimates for a mining vessel capable of dredging manganese nodules. The second reason is that the procedure selected for estimating the cost of the dredge depends on a set of graphs presented by Professor Harry Benford in an article entitled "Ocean Ore-Carrier Economics and Preliminary Design" (2).

In this article Benford graphs relationships between ship characteristics such as displacement, horsepower, deadweight tons and cubic number with ship costs.

To estimate a value for the surface vessel which would support the hydraulic dredging equipment, certain ship characteristics are therefore needed. In his book, The Mineral Resources of the Sea, John L. Mero presents a series of calculations for the weight of the dredging equipment, the horsepower requirements, and the cost of the equipment per foot of depth. These calculations are based on a depth of 10,000 feet, but they can be adjusted for different depths. In this analysis a depth of 18,000 feet was assumed, and Mero's formulas were adjusted for this value. The cost data which Mero reported was updated with a price index of 1.4, and a cost estimate of $6,500,000 was obtained for the dredge equipment. Using Benford's graphs and a price index of approximately 1.4, the cost of the ship was calculated at approximately $10,000,000. The total cost of the mining unit would therefore be $16,500,000.

Phase One - Cost Estimation (See Appendix A for computer program.)

The computerized portion of this model is written in Fortran for the Univac 1108 computer. The input values that are needed for the program are listed below:

(1) SS = The speed of the transport vessels in knots

(2) WRM = The fraction of material lost as waste during the mining operations.

(3) LD = The length of the development period in years

(4) NYB = The length of long term loans (in years)

(5) NS = The length of short term loans (in years)

(6) I1 = The interest rate for short term borrowing

(7) I2 = The interest rate for long term borrowing

(8) SM = The horsepower of the mining vessel

(9) CNM = Cubic number for the mining vessel

(10) DSM = The displacement of the mining vessel

(11) CDT = The number of tons of cargo that can be carried by the barges

(12) S = The distance from the deposit to its shore based processing facility (in nautical miles)

(13) DST1 = The displacement of the barges

(14) CNT1 = Cubic number for the barges

(15) CNT2 = Cubic number for the tugs

(16) ST2 = Tug horsepower

(17) CM = Cost of the mining unit

(18) DQ = Cost of the dredge equipment

(19) VM = Tons of ore mined per year

(20) G = Ratio of tugs needed per barge

(21) XM, XN, XC, XB = The concentrations of manganese, nickel, copper and cobalt in the nodules mined

(22) PM, PN, PC, PB = The market price for manganese, nickel, copper and cobalt respectively

The numbered circles of Figure 2 represent the operations which are performed to estimate the cost parameters of the model. The first operation, which has already been discussed, is the estimation of the dredge cost. Following is a brief outline of the remaining operations.

<u>Operation 2</u> - Tons of Ore Transported

$$VT = VM(1 - WRM)$$

$$WM = X(VM)$$

where: X = cost per ton for waste disposal at mine site

WM = annual waste disposal cost at the mine site

VT = tons of ore transported

Operation 3 - Transport Vessel Cost

$$RTD = (2(S)/24(SS)) + 4$$

$$TPY = 350/RTD$$

$$NS1 = VT/(TPY)(CDT)$$

$$NS2 = (NS1)(G)$$

$$RT = VT/CDT$$

$$CT = NS1(\$550{,}000)$$

where: RTD = number of days in a round trip for transport vessels assuming 2 port days and 2 loading days

TPY = number of trips per year that can be made by a transport vessel

$NS1$ = number of barges needed

$NS2$ = number of tugs needed

RT = total number of round trips needed to deliver all of the annual production

CT = cost of the barges

Assumptions: (1) TPY is based on 350 operating days per year

(2) CT is based on an estimated cost for each barge of $550,000. This factor must be changed for barges of significantly different size. The barges used in this analysis can carry approximately 10,000 tons of ore (22).

Operation 4 - Single Value Estimates (23) and (13)

$$CF = \$5{,}000{,}000$$

$$T(LD-1) = \$8{,}000{,}000 \text{ all other } T(J) = 0$$

$$EC(1) = EC(2) = \$3{,}000{,}000 \text{ all other } EC(J) = 0$$

where: CF = cost of port facilities

T(J) = cost of tests and trials of equipment in year j

EC(J) = exploration cost in year j

LD = length of development period

Operations 5, 6, 7 and 14 - Operating and Overhead Cost for Mining(26).

$$SCM = 1.25(13(CNM/1000)^{1/6} + 12(SM/1000)^{1/5} - 12)$$

$$ML = SCM(\$15{,}000)$$

$$MS = \$80(SCM/10)^4 + \$0.02(7200)(SM)$$

$$MM = \$10{,}000(CNM/1000)^{2/3} + \$4500(SM/1000)^{2/3} + 0.05(DQ)$$

$$OCM = ML + MS + MM$$

$$MO = (1/9)OCM$$

where: OCM = operating cost for mining

SCM = size of the crew for the mining vessel

ML = annual labor cost for mining

MS = fuel and supply cost for mining

MM = mining maintenance and repair cost

DQ = cost of the dredge equipment

MO = mining overhead

Assumptions: (1) ML is based on an estimated annual wage of \$15,000 per man

(2) MS is based on an estimated power cost of \$0.02 per horsepower - hour

(3) MM is based on a figure for maintenance of the ship plus approximately 5 per cent of DQ for maintenance of the dredge equipment

Operation 8 - Processing and Marketing Costs

$$CP = (VT/1{,}800{,}000)^{0.6}\ (\$60{,}000{,}000)$$

$$WPI = (0.1)CP$$

$$WPA = (\$1)VT$$

$$OCP = (\$15)VT$$

$$PO = (1/9)OCP$$

$$M = (1/4)(OCP + PO)$$

$$LA = (\$5)VT$$

where: CP = cost of the processing facility

WPI = cost of waste disposal equipment at processing plant

WPA = annual waste disposal cost at processing plant

OCP = operating cost of process facility

PO = overhead of process operations

M = marketing cost

LA = lease acquisition cost

Assumptions: (1) The process facility cost is based on an estimated cost of $60,000,000 for a 1,800,000 ton per year operation. The formula used is an approximate measure of cost for different size production facilities (7).

(2) WPI is based on a value of approximately 10 per cent of the process facility cost

(3) WPA is estimated to be \$1 per ton of ore processed

(4) OCP is estimated to be \$15 per ton of ore processed. Estimates for this quantity have ranged from \$5/ton to \$30/ton

(5) Overhead is assumed to be 10 per cent of the total processing cost

(6) Marketing costs are estimated to be 20 per cent of total processing and marketing cost

(7) LA is based on a 5 per cent royalty for the ore which is processed. The value of a ton of ore is estimated to be \$100

Operation 9 - Gross Revenue

$$VMN = (VT)(XM)(.95)$$

$$VN = (VT)(XN)(.95)$$

$$VC = (VT)(XC)(.95)$$

$$VB = (VT)(XB)(.95)$$

$$GR = (VMN)(PM) + (VN)(PN) + (VC)(PC) + (VB)(PB)$$

where: VMN = tons of manganese produced

VN = tons of nickel produced

VC = tons of copper produced

VB = tons of cobalt produced

GR = gross revenue

Assumptions: (1) The recovery percentage for all of the minerals is assumed to be 95 per cent (6)

Operations 10,11, 12, 13, and 15 - Transportation Costs (26).

$$TM = (\$10,000(CNT1/1000)^{2/3} + 40,000)(NS1)$$

$$+ (\$10{,}000(CNT2/1000)^{2/3} + \$4500(ST2/1000)^{2/3})(NS2)$$

$$TL = \$15{,}000(NS1(0) + NS2(13))$$

$$TF = (\$670)(350)(NS2) + \$1000 + \$80(DST1/1000)(RT)$$

$$TH = (\$50{,}000 + 12(DST1/1000))(NS1 + NS2) + (\$1500)(350)(NS2)$$

$$OCT = TM + TL + TF$$

where: TM = transport maintenance and repair cost

TL = transport labor cost

TF = transport fuel cost plus port fees

TH = transportation overhead cost

OCT = transportation operating cost

Assumptions: (1) TL is based on a crew of 13 men for each tug and 0 men for each barge. Annual wages are assumed to average $15,000 per man

(2) TF is based on a fuel cost of $670 per day and port fees

(3) TH includes an assumed $1500 per day charter fee for tugs

<u>Operation 16</u> - Start Up and Initial Overhead Costs

$$SU(LD) = .25(ML + TL + .3OCP + .5M) + .1\ (OCM + OCT + OCP) \text{ all other } SU(J) = 0$$

$$(IO(J),J{=}1,LD) = .1(EC(J) + T(J) + CM1(J) + CT1(J) + CP1(J) + SU(J)) \text{ all other } IO(J) = 0$$

where: SU(J) = start up cost in year j

IO(J) = initial overhead in year j

CM1(J),CT1(J),CP1(J) = capital costs of mining, transportation and processing equipment respectively

Assumptions: (1) SU(LD) is based on 25 per cent of the annual labor cost and 10 per cent of the annual operating costs

(2) IO(J) is based on 10 per cent of the capital costs incurred in the development years

Operation 17 - Insurance and Depreciation Expenses (1)

$$INS(J) = DM(J)(.03)((LME + 1)/2LME) + DT(J)(.03)((LTE + 1)/2LTE) + DP(J)(.03)((LPE + 1)/2LPE)$$

$$D(J) = DM(J)/LME + DT(J)/LTE + DP(J)/LPE + DX1(J)$$

where: INS(J) = insurance cost in year j

D(J) = depreciation expense in year j

LME, LTE, LPE = lives of the mining, transport, and processing equipment respectively

DM(J), DT(J), DP(J) = capital costs of the mining, transport and processing equipment respectively

DX1(J) = depreciation expense of other equipment

Assumptions: (1) The average annual insurance rate is 3 per cent

(2) Straight line depreciation is used

(3) Seventy per cent of the exploration and test costs are depreciated over the life of the investment and included as DX1(J)

Operation 18 - Miscellaneous Annual Expense

$$MAE(J) = .3(EC(J) + T(J))$$

where: MAE(J) = miscellaneous annual expense in year j

Assumptions: (1) Thirty per cent of the exploration and test costs are assumed to be non-depreciable expenses and are treated as miscellaneous costs.

Phase Two - Economic Analysis

After the cost factors have been estimated by phase one of the computer model, the second phase can begin. The purpose of this phase is to develop the expected cash flows for each year of the ocean mining investment. This objective can be accomplished through the use of the cost estimates provided by phase one and a set of assumed economic conditions. Figure 3 shows the basic relationships which were assumed for this study.

The economic system outlined by Figure 3 is broken down into two distinct sections. The first section applies during the development years of the project, and the second section applies after production starts. The development period lasts for LD years. The total length of the project is designated by the variable LP in the program and is assumed, as a general rule, to be five times the length of the development period.

During the development period capital for purchasing assets and paying initial expenses is assumed to flow from three different sources; ownership, long term borrowing, and short term borrowing. Ownership and long term borrowing are calculated as percentages of the cash needed for working capital and the purchase of physical assets. This percentage varies from year to year and is dependent on the assets that the firm can use as collateral. For the case of Pacific Ocean manganese nodules the following relationships were used:

$$O(J) = .333\ TA(J) + WCO(J) \qquad (J = 1,2,3)$$

$$O(J) = .25\ TA(J) + WCO(J) \qquad (J = 4)$$

$$LTB1(J) = .667\ TA(J) + WCB(J) \qquad (J = 1,2,3)$$

$$LTB1(J) = .75\ TA(J) + WCB(J) \qquad (J = 4)$$

where: $O(J)$ = increase in ownership in year j

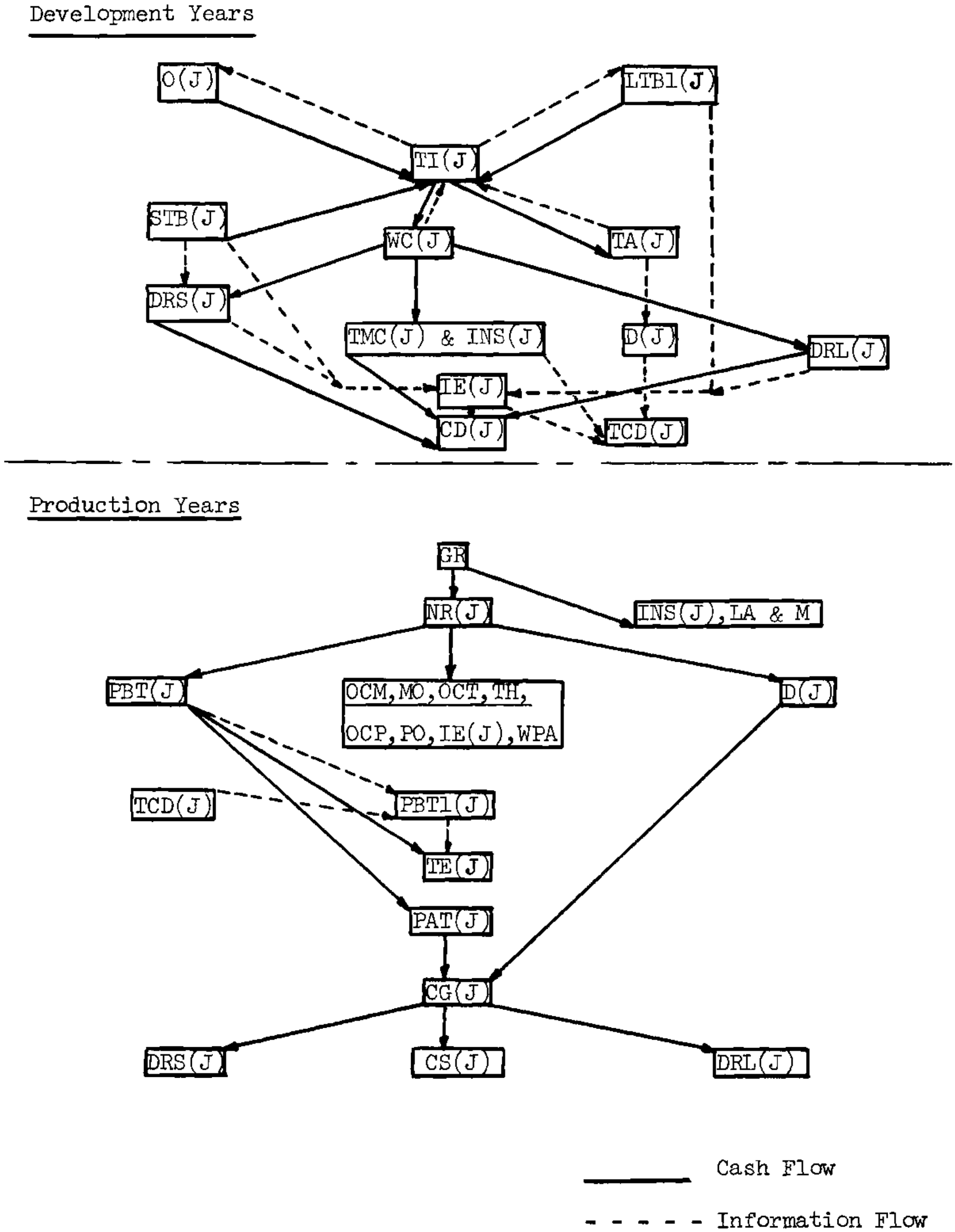

Figure 3. Economic Analysis

TA(J) = cost of assets acquired in year j

WC(J) = working capital needed in year j

WCB(J) = the portion of working capital that is borrowed in year j

LTB1(J) = increase in long term borrowing in year j

WCO(J) = the portion of working capital supplied through ownership

The third source of cash, short term borrowing, is used to keep the project in operation when the available working capital is insufficient to cover the costs incurred during a year. It is assumed that the firm will be able to make short term loans in the years where the estimated working capital is less than the cash deficit.

In the case of manganese nodule deposits, the working capital provided for each year is based on a percentage of the assets acquired during that year. The following relationships were used for this analysis.

$$WC(1) = TA(1)$$

$$WC(2) = TA(2)$$

$$WC(3) = .333\ TA(3)$$

$$WC(4) = .250\ TA(4)$$

$$WC(J) = 0 \quad J = 5, \ldots.\ LP$$

The initial costs which must be paid with working capital are the initial overhead expenses, the interest expenses on long and short term loans, insurance, start up costs, long and short term debt retirement, and miscellaneous annual expenses. Phase one of this model provided estimates for all of these costs except the interest and debt retirement expenses. Below are the relationships used to estimate these costs:

$$1E(J) = \left(\sum_{n=1}^{J-1} STB(J) - \sum_{n=1}^{J-1} DRS(J) \right) I1 + LTB(J)\ I2$$

$$DRL(J) = LTB1(J-1)/NYB + LTB1(J-1)/NYB + \ldots + LTB1(J-NYB)/NYB$$

$$DRS(J) = STB(J-1)/NS + STB(J-2)/NS + \ldots + STB(J-NS)/NS$$

where: 1E(J) = interest expense in year j

DRL(J) = long term debt retirement in year j

DRS(J) = short term debt retirement in year j

STB(J) = short term loan in year j

NYB = length of long term loan

NS = length of short term loan

I1 = interest rate for short term loan

I2 = interest rate for long term loan

LTB(J) = long term loans outstanding in year j

As there is no revenue generated in the development years of the project, the sum of the depreciation, insurance, interest, start up costs and miscellaneous annual expenses of a year is considered as the loss incurred in that year. The sum of the losses sustained in the initial years can be used as a tax allowance when production starts and profits are generated. Variable TCD(J) in the model represents the sum of these losses.

The actual cash amount that was required by the project during these years when no revenue is being generated is called the cash deficit, CD(J). This variable is equal to the losses reported for a year, TCD(J), plus the depreciation expense and minus the debt retirement payments. The depreciation represents a book cost and not a cash outlay, therefore, it is not included in the cash outlay.

After the development period has ended the revenues generated by the sale of minerals should be sufficient to pay all of the expenses of the operations and provide profits for the mining firm. To determine the profit before tax in any year the following relationships are used:

$$NR(J) = GR - INS(J) - LA - M$$

$$PBT(J) = NR(J) - (OCM + MO + OCT + TH + OCP + PO + WPA) - D(J) - IE(J)$$

where: $NR(J)$ = net revenue in year j

$PBT(J)$ = profit before tax in year j

The taxable profit before tax, PBT1(J), is calculated by subtracting the tax allowances from the profit before tax. In this model the only tax allowance which is considered is the sum of the losses incurred, TCD(J). Losses can only be used as tax allowances once, therefore, TCD(J) is diminished by the amount used as a tax allowance in any year.

The tax expense for the mining firm, TE(J), is approximated by a value equal to 50% of the taxable profit before tax. This leaves a profit after tax, PAT(J), equal to the profit before tax minus the tax expense.

The actual cash amount generated by the mining operations is equal to the profit after tax plus the depreciation expense. This relationship exists because the depreciation expense is only a book cost used for tax discount purposes. Cash generated, CG(J), thus more accurately defines the cash which the mining firm will have available after taxes have been paid. This cash is used to retire long and short term debts and to provide profits for the firm, CS(J).

Output Format

An outline of the output format for the economic analysis is

ELEMENT	1	2	. . . . .	LP
TA				
WC				
O				
LTB1				
TI				
OW				
LTB				
TOTI				
STB				
BVA				
VT				
GR				
INS				
M				
LA				
NR				
OCM				
MO				
OCT				
TH				
OCP				
PO				
WPA				
D				
TMC				
IE				
PBT				
TCD				
PBT1				
TE				
PAT				
D				
CG				
DRL				
DRS				
CS				
CD				
RO				
RI				

Figure 4. Output Format

presented in Figure 4. The column headed "ELEMENT" contains the cost and revenue factors included in the analysis. The remaining columns are headed by a particular year. The values in these columns correspond to the element name in their row. The last two rows of the computer printout correspond to the two measures of economic worth incorporated in the model.

Table 6 contains a listing of the definitions of the symbols used in the output format.

Table 6. Output Symbols

TA	=	cost of assets acquired
WC	=	working capital needed
O	=	increase in ownership
LTB1	=	long term loan
TI	=	increase in total investment
OW	=	cumulative value of ownership
LTB	=	long term debt level
TOTI	=	cumulative total investment
STB	=	short term loan
BVA	=	book value of assets
VT	=	tons of ore transported
GR	=	gross revenue
INS	=	insurance
M	=	marketing cost
LA	=	lease acquisition

Table 6. Output Symbols (cont'd)

NR	=	net revenue
OCM	=	operating cost of mining
MO	=	mining overhead
OCT	=	operating cost of transportation
TH	=	transport overhead
OCP	=	operating cost of processing
PO	=	process overhead
WPA	=	waste disposal cost
D	=	depreciation
TMC	=	total of IO(J), MAE(J) and SU(J)
IE	=	interest expense
PBT	=	profit before tax
TCD	=	cumulative tax allowance
PBT1	=	taxable profit before tax
TE	=	tax expense
PAT	=	profit after tax
D	=	depreciation
CG	=	cash generated
DRL	=	long term debt retirement
DRS	=	short term debt retirement
CS	=	cash surplus
CD	=	cash deficit
RO	=	rate of return on ownership
RI	=	rate of return on investment

CHAPTER VI

TESTS OF THE ECONOMIC MODEL

In order to test the operation of the model, Pacific Ocean manganese nodule deposits were chosen as the test case. These deposits were selected because there is more information available concerning them than almost any other ocean deposit. They are also considered by many experts to be one of the more probable deposits for initial deep sea mining operations. In addition, manganese nodule deposits are located in deep water, 12,000 to 18,000 feet, and are far from land, approximately 4000 nautical miles. They will thus be exposed to many of the environmental conditions of the ocean.

The cost estimation phase of this economic model, as was outlined in the previous chapter, is prepared for the manganese nodule case. The tests which are run with the model consist of varying several of the economic parameters inputed to the model. The parameters which were selected for analysis are: (1) the prices of the minerals; (2) the annual mining production; (3) the payback period for long term loans and (4) the cost of the mining equipment.

Assumptions concerning the nature of the Pacific Ocean manganese nodule deposits were made in order to provide a structure around which the tests could be organized. These assumptions were:

(1) A development period of four years was assumed for construction and organization of the mining operation.

(2) The nodules are located approximately 4000 nautical miles

from the shore based on processing facility and are in depths of water between 12,000 and 18,000 feet.

(3) The nodules must be transported to a shore based processing facility before they can be marketed.

(4) The following concentrations (dry weight) are assumed for the nodules: Mn, 29.0 per cent Ni, 1.5 per cent, Cu, 1.9 per cent; Co, 0.2 per cent.

(5) Process recovery percentages for all four minerals were assumed to be 95 per cent.

(6) An hydraulic dredging system based on a surface vessel was expected.

(7) The transport system is assumed to be composed of barge-tug units with cargo capacities around 10,000 tons.

Test One - Price Fluctuations

Future prices for the four principal minerals contained in manganese nodules will be determined by the market supply and demand conditions. At the time of this study manganese ore containing 48 per cent MnO_2 is valued at approximately $0.03 per pound, nickel is valued at $1.33 per pound, copper at $0.57 per pound and cobalt at $2.20 per pound (19). Since substantial quantities of these minerals will be produced by the ocean mining operation, resulting decreases in prices may be forthcoming. In order to anticipate the economic effects of price changes, a test of the model was conducted with prices 20 per cent below their present values, and a comparison was made of these results and the results obtained with actual prices. On the basis of dollars per ton the following list outlines the data for the computer test.

Mineral	Present Price	-20 per cent
Manganese	$123	$98
Nickel	2660	2128
Copper	1154	923
Cobalt	4400	3520

The computer results of this test are shown in Figure 5 and 6. These two figures are graphs of the rate of returns earned through a particular year of the project. Figure 5 represents the normal case, or the case in which actual prices and estimated costs were used. If prices decrease by 20 per cent and other economic factors remain constant, the mining firm could expect changes of the nature evident in the transition between Figure 5 and Figure 6. A comparison of these two figures shows that the market prices of the minerals is an extremely important economic parameter. A decrease in prices of 20 per cent resulted in a decrease in the rate of return on ownership of 26 per cent over a twenty year period. This price decrease also affected the rate of return on total investment, decreasing it by 10 per cent.

The charts of Figure 7 and 8 provide additional insights into the nature of the changes experienced in the economic system when the mineral prices were decreased. Figure 7 and 8 show the changes in the rate of return on ownership for the normal case and the reduced price case, respectively. During the first year of production the rate of return for the normal case jumped from - 100 per cent to + 26 per cent, an increase of 126 per cent. During the corresponding year for the reduced price case the rate of return changed only 100 per cent, rising from -100 per cent to 0 per cent. The difference in the rate of returns

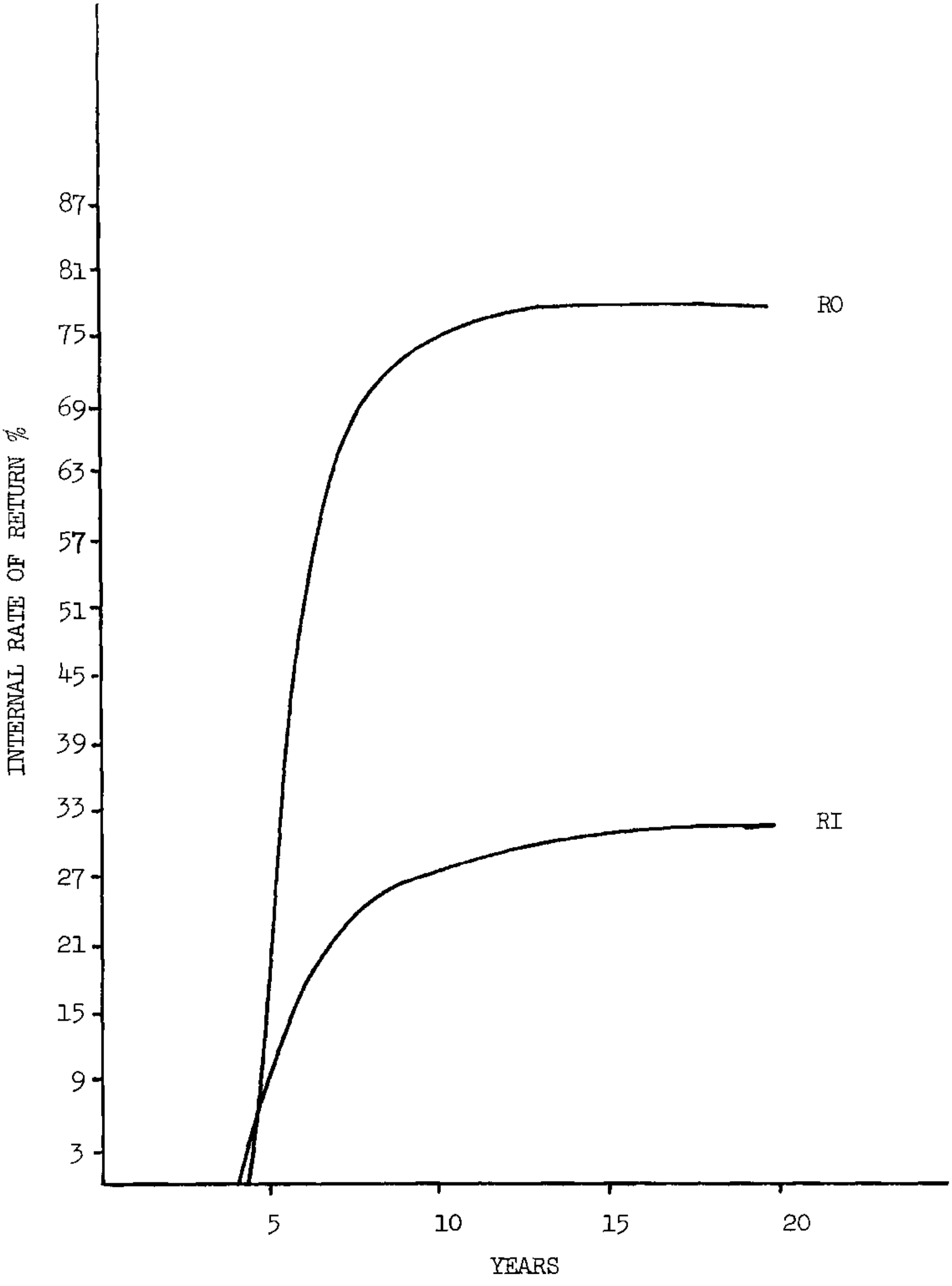

Figure 5. Normal Case - Rate of Return Curves

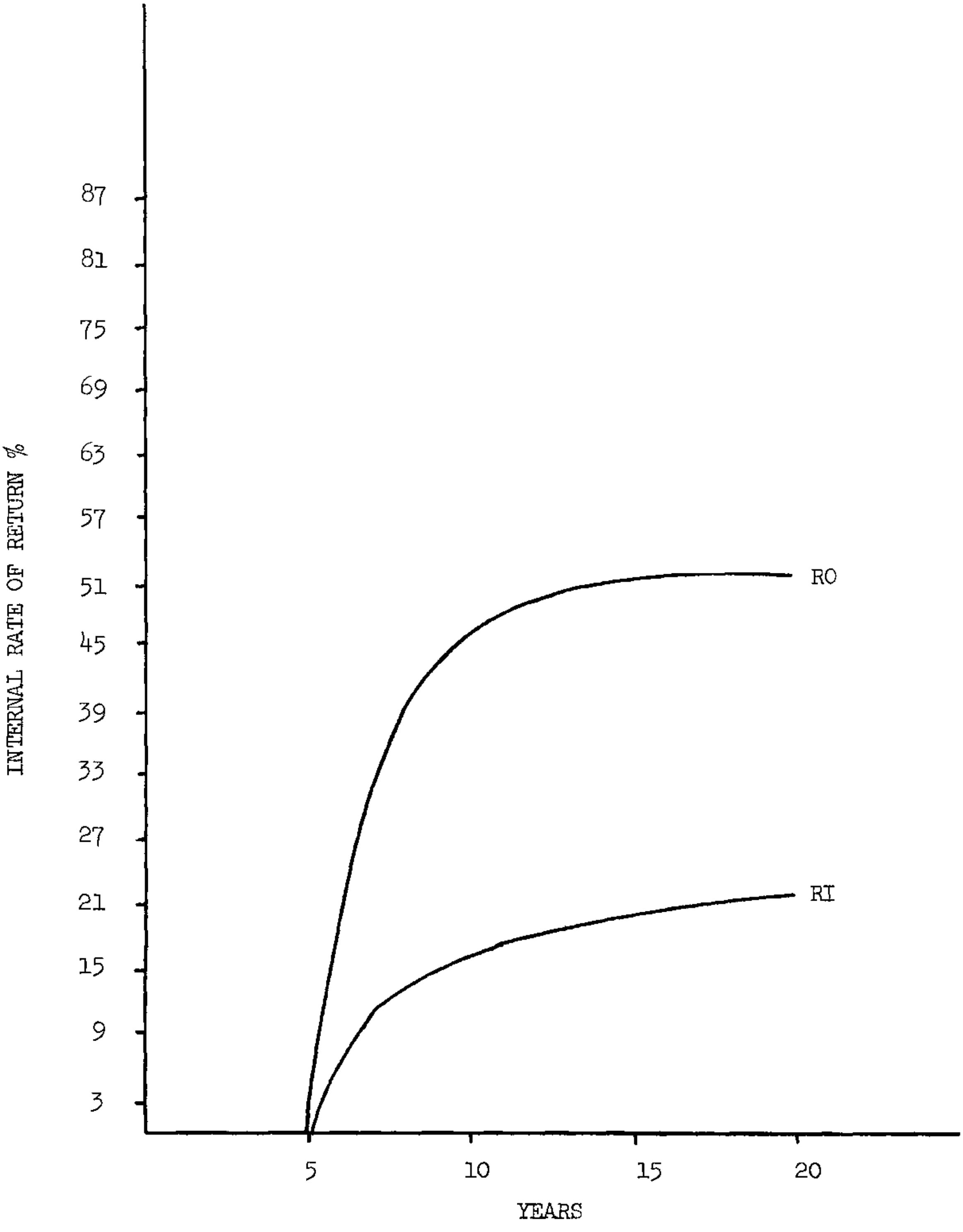

Figure 6. Price Fluctuations - Rate of Return Curves

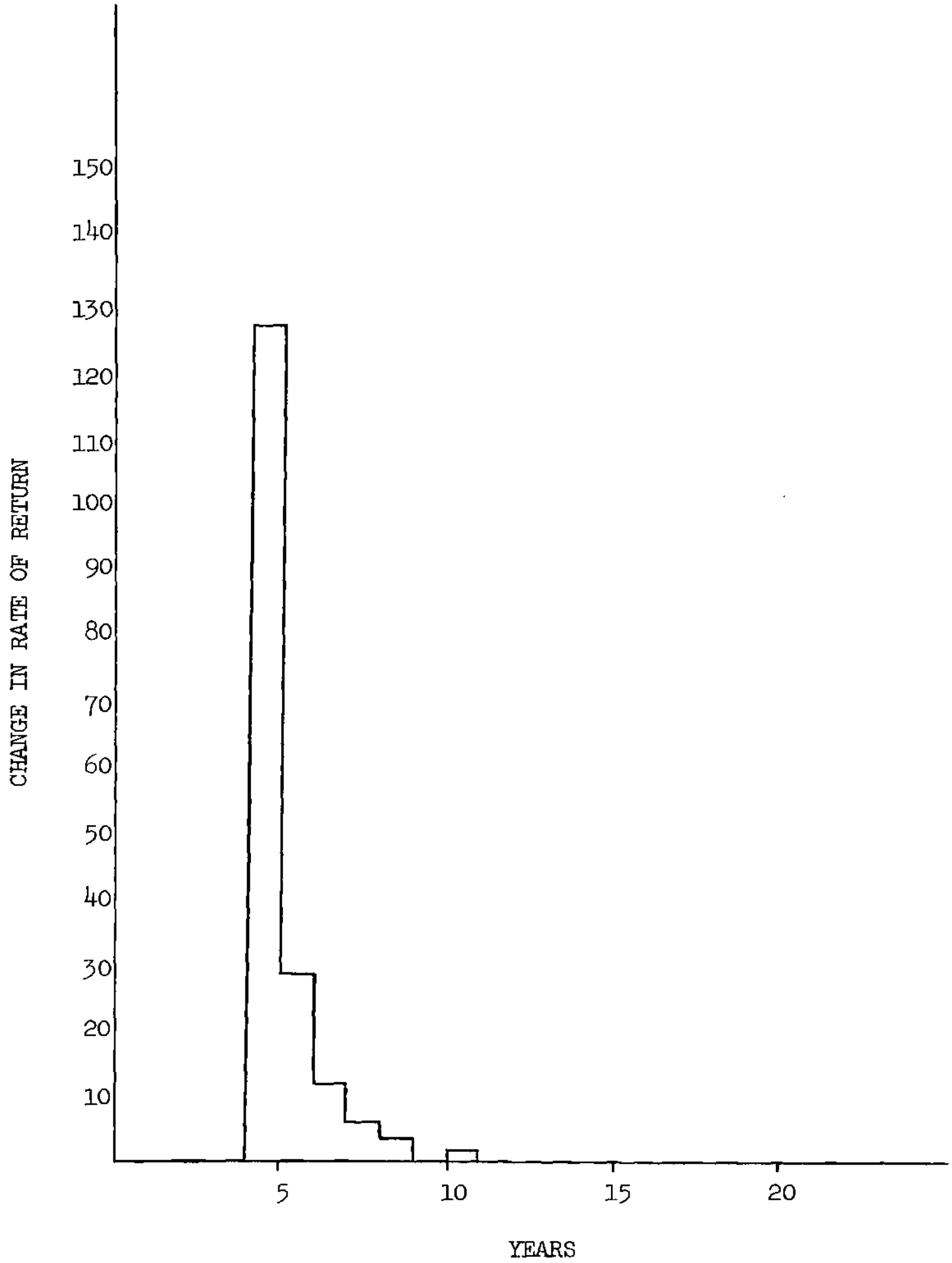

Figure 7. Normal Case - Change in Rate of Return

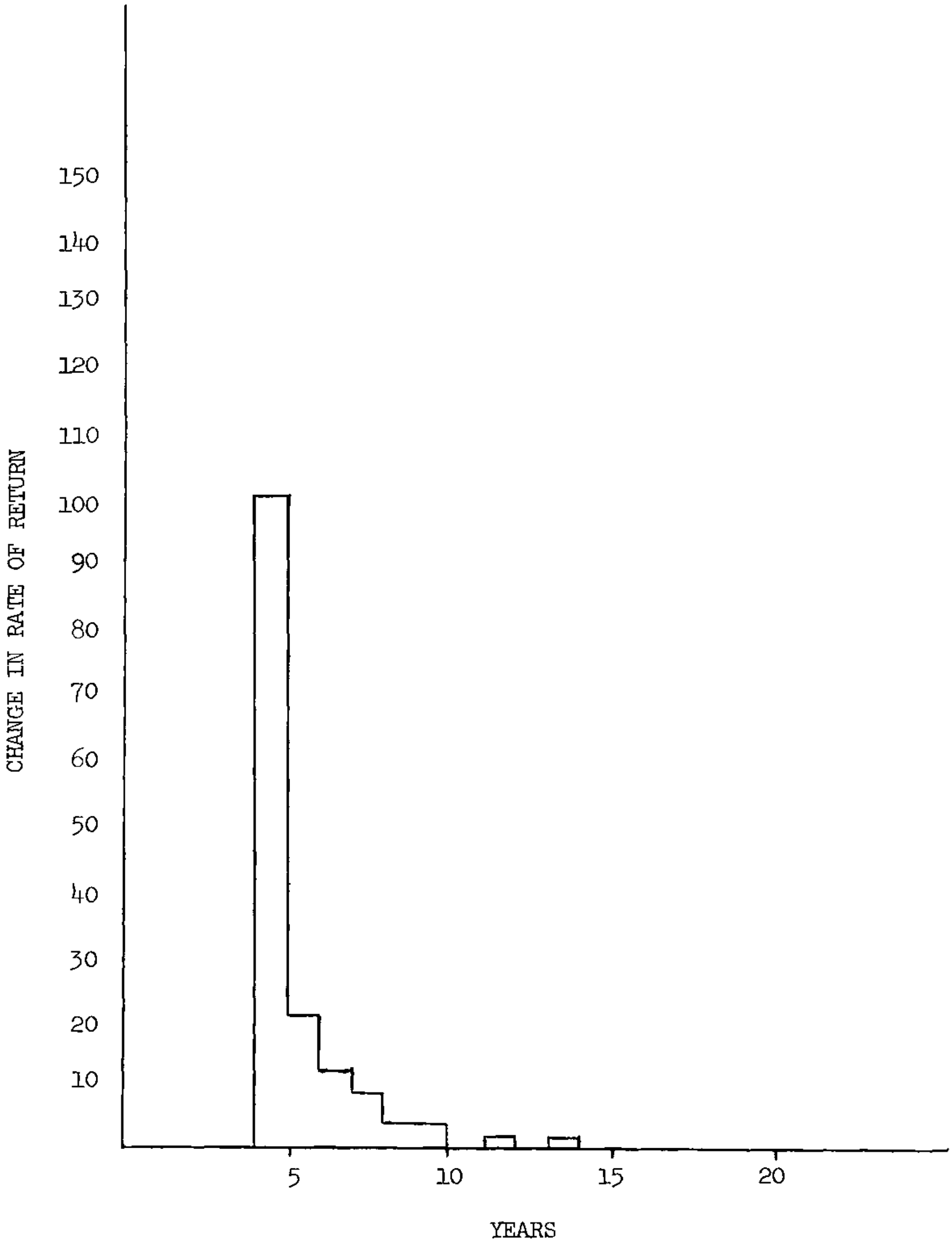

Figure 8. Price Fluctuations - Change in Rate of Return

for the two cases at this point in time was 26 per cent.

The computer output for this test and the remaining tests is included in Appendix B. An examination of this output shows that the 20 per cent price decrease cost the mining firm approximately $15,000,000 per year in profits.

Test Two - Mining Production

Another major factor in the economic system of an ocean mining operation is the number of tons of ore which are extracted from the sea floor during yearly operations. Values of 1,000,000 to 1,500,000 tons of nodules have been suggested as practical for manganese nodule mining. A test of this parameter has been made with a yearly production value of 1,000,000 tons. The results of this test can be compared with the normal case which is based on a 1,500,000 ton operation.

Figure 9 shows the results of the test made with a 33 per cent decrease in production. The rate of returns on ownership reached a value of 60 per cent after twenty years, 18 per cent below the 78 per cent figure attained in the normal case. The difference in the rate of return on total investment was 6 per cent in favor of the normal case.

Figure 10 is the chart of changes in rate of return on ownership for the reduced production case. After two years of production, the rate of return for this case was 20 per cent behind the rate of return for the normal case.

This analysis indicates that high throughputs are economically desirable for ocean manganese nodule mining. The economic effects of lower production rates are not as significant as those of lower prices, but annual production is still an important economic factor.

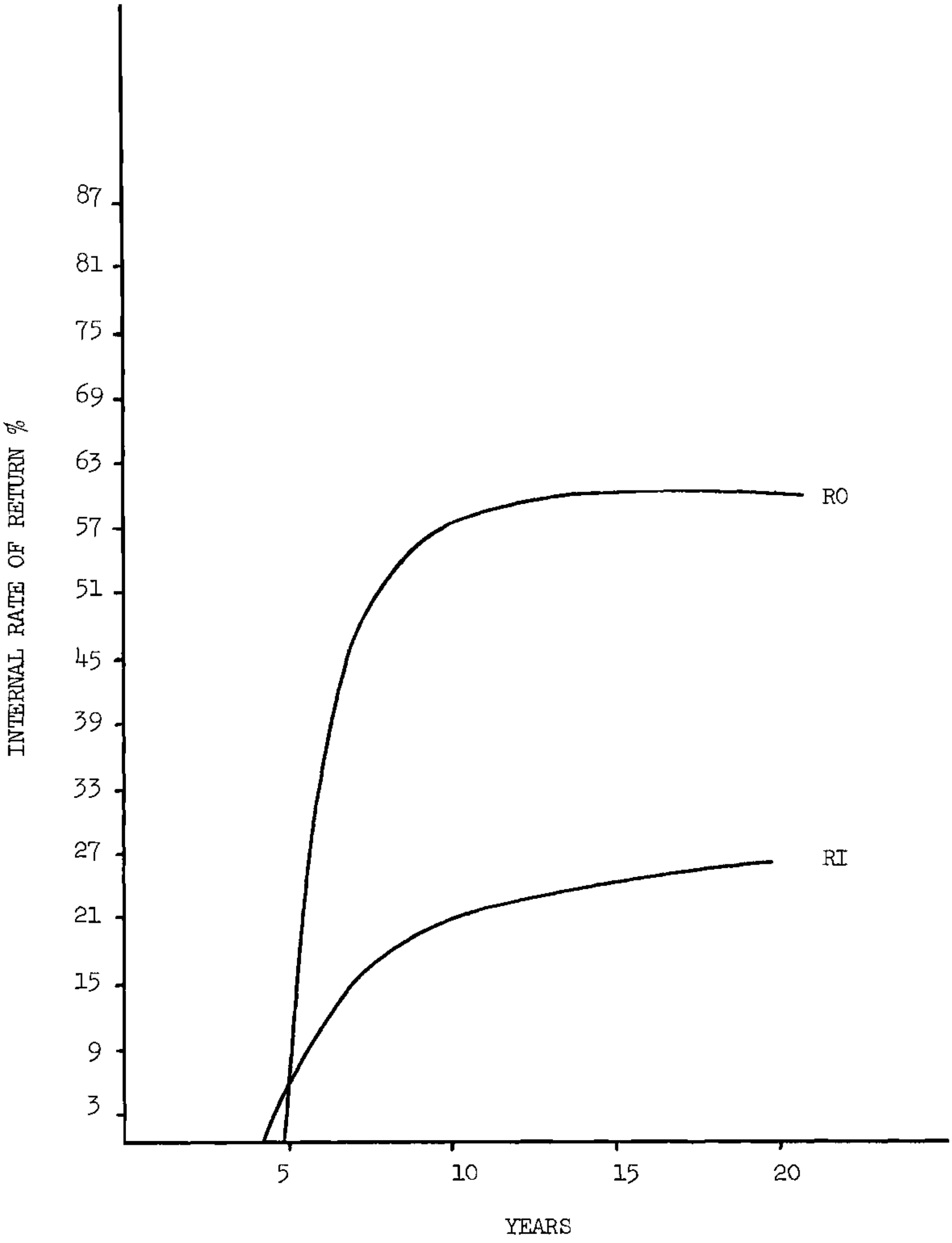

Figure 9. Annual Production - Rate of Return Curves

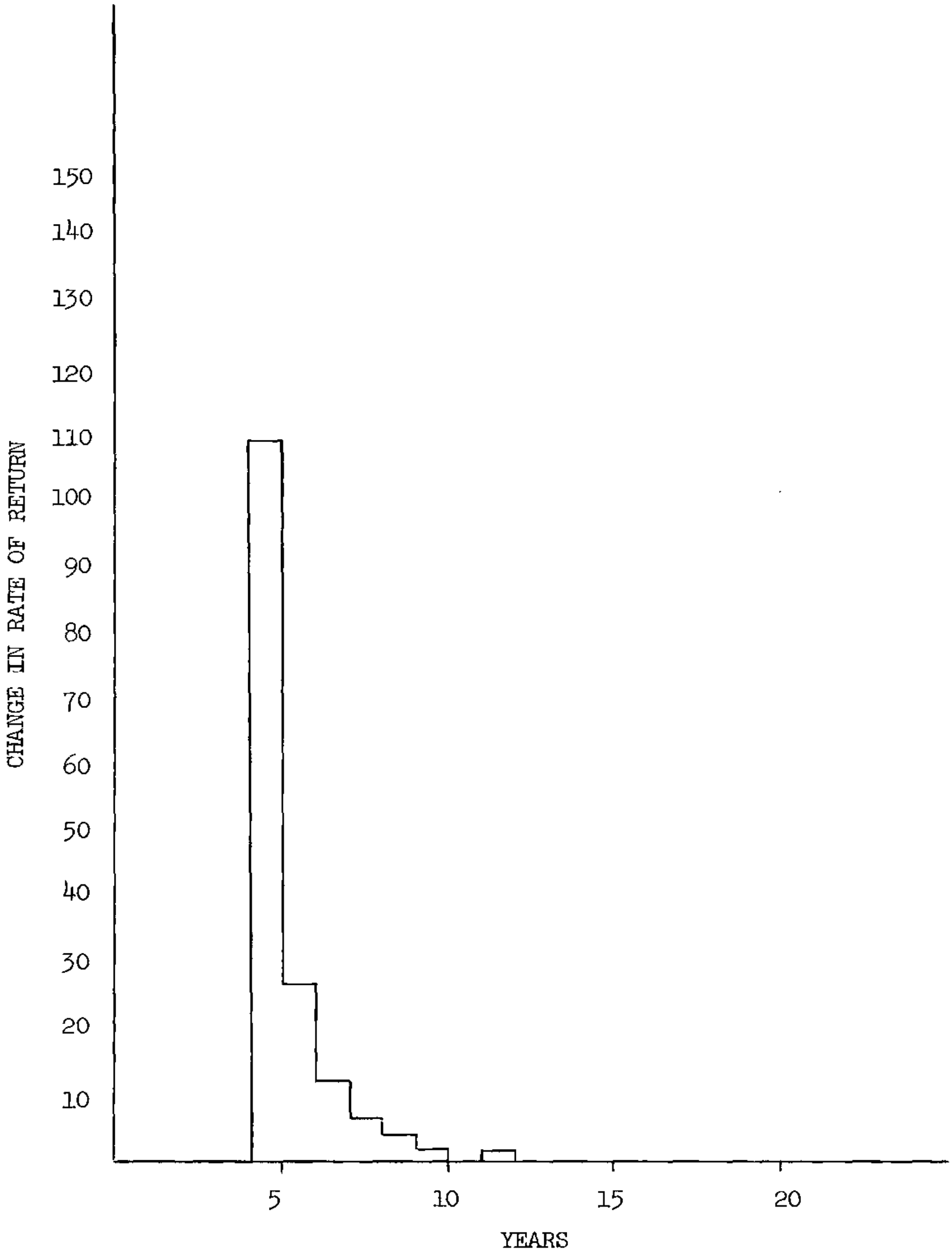

Figure 10. Annual Production - Change in Rate of Return

Test Three - Cost of Mining Vessel

The estimated cost of a mining vessel capable of recovering manganese nodules from the depths of the ocean has been one of the most variable elements in the economic studies of the past. These estimates have ranged from $5,000,000 (18) to $150,000,000 (23). In order to test the importance of this estimate to the economic justification of the investment, a test was run with an increase in the mining vessel cost of 400 per cent. The normal case was based on an estimated mining vessel cost of $16,500,000, therefore, this test was made with an $82,500,000 estimate.

The results of this test are plotted in Figure 11. The curves of this figure are very similar to those obtained for the case of a price reduction. The rate of return on ownership reaches a maximum value of 50 per cent after twenty years. This compares with the maximum value of 52 per cent obtained in the reduced price case.

An analysis of the computer output for the reduced price case and this case, however, reveal some interesting differences in the cash flows of the projects. The cash surpluses for the case based on an $82,500,000 mining vessel vary from $8,000,000 to $15,000,000 more per year than the reduced price case. The reason lower rates of return are generated by this case is the fact that the ownership and total investment factors are considerably greater.

In the first year of operation the profits generated by the case with the higher mining vessel cost are actually greater than the profits generated by the normal case. This situation exists because the normal case had a smaller tax allowance, and thus was required to pay higher taxes.

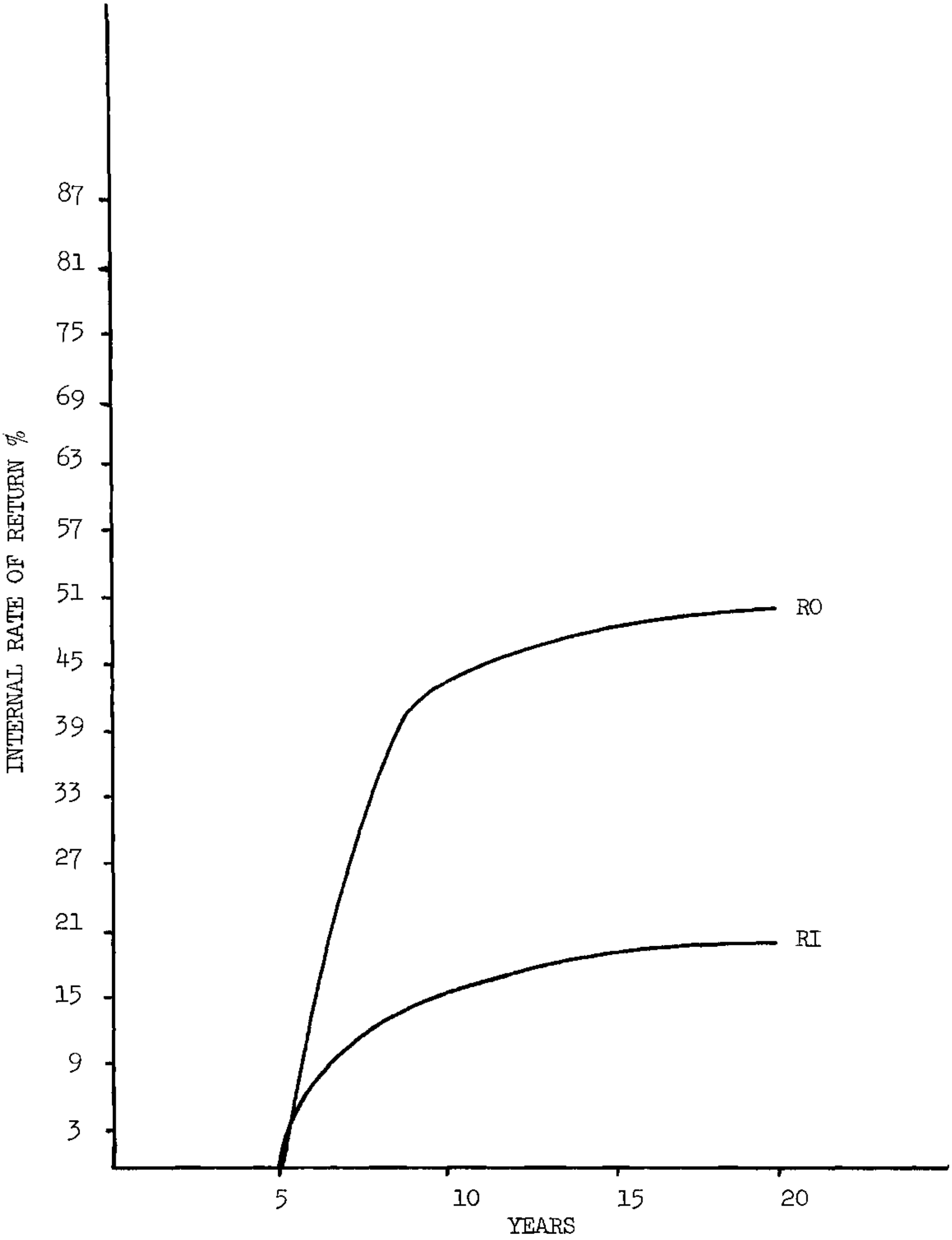

Figure 11. Mining Vessel Cost - Rate of Return Curves

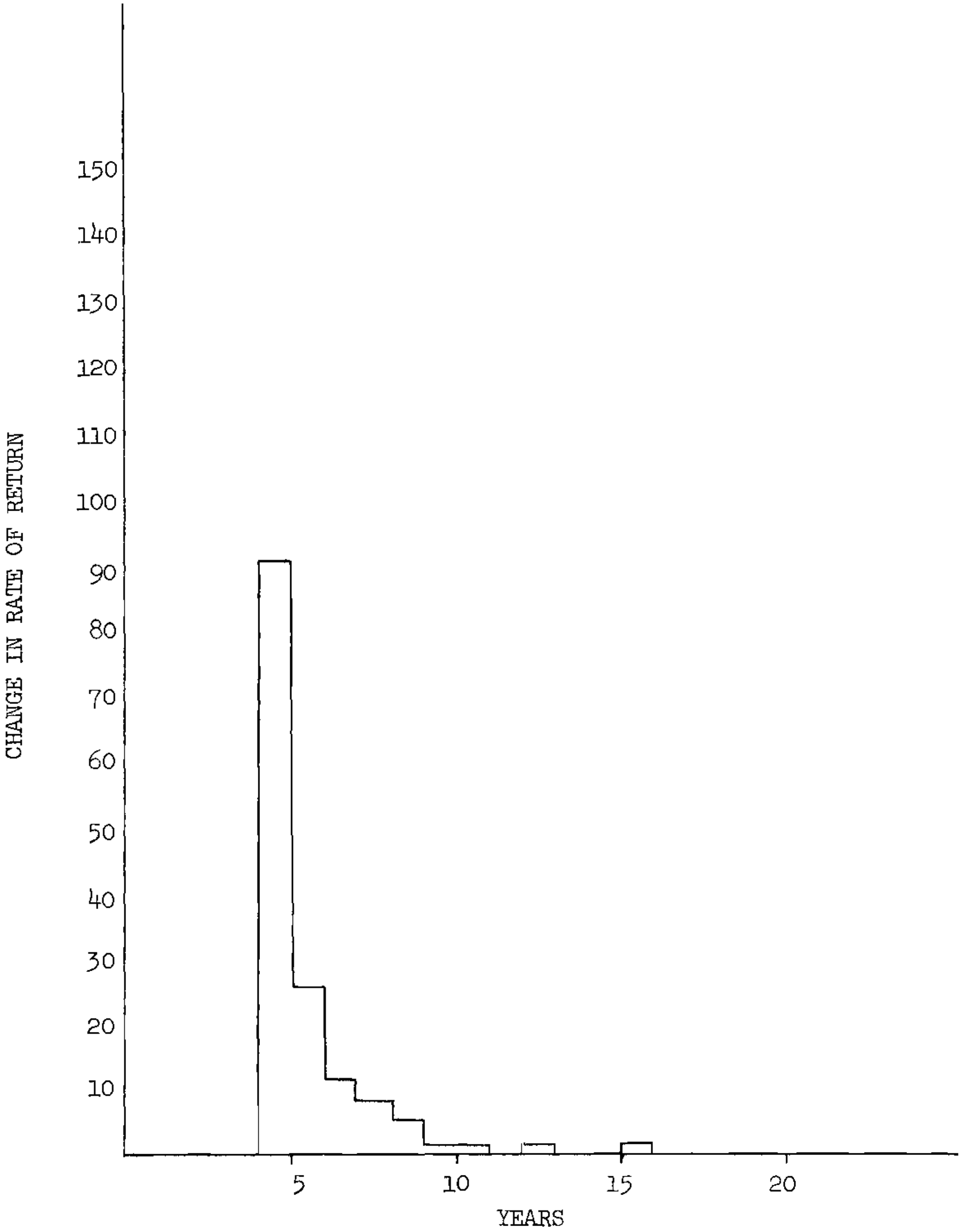

Figure 12. Mining Vessel Cost - Change in Rate of Return

In the second through the eighth year the profits of the normal case were approximately $7,000,000 more than this case. This was due to the higher debt retirement payments for the more expensive mining vessel. After the eighth year of operation, however, long term debts had been paid and the profits for the two cases were approximately the same.

This analysis reveals that while the cost of the mining vessel is an important factor, it is reduced in importance by the tax structure of the United States. If mining vessels actually reach the cost levels of $100,000,000 or more, the economic desirability of manganese nodule mining would certainly suffer, but for costs around $20,000,000 favorable rates of return appear to be obtainable.

Test Four - Length of Long Term Loans

The fourth test run with this model involved an increase of 50 per cent in the length of long term loans. This changed the payback period for long term debts from the 8 year figure used in the normal case to a 12 year figure used in this case. The rate of return curves which were obtained under these conditions are shown in Figure 13. The effect which this change had on the measures of economic worth of the investment was to increase the rate of return on ownership by 6 per cent and to leave the rate of return on total investment unaffected.

These effects should be expected because a change in the length of loans would primarily benefit the mining firm by allowing it to receive larger profits in the initial years and smaller profits in later years. This would benefit the firm due to the time value of money. The reason the rate of return on total investment is unaffected is because the increased profits in the initial years is offset by higher long term loans outstanding, and thus a higher value for total investment.

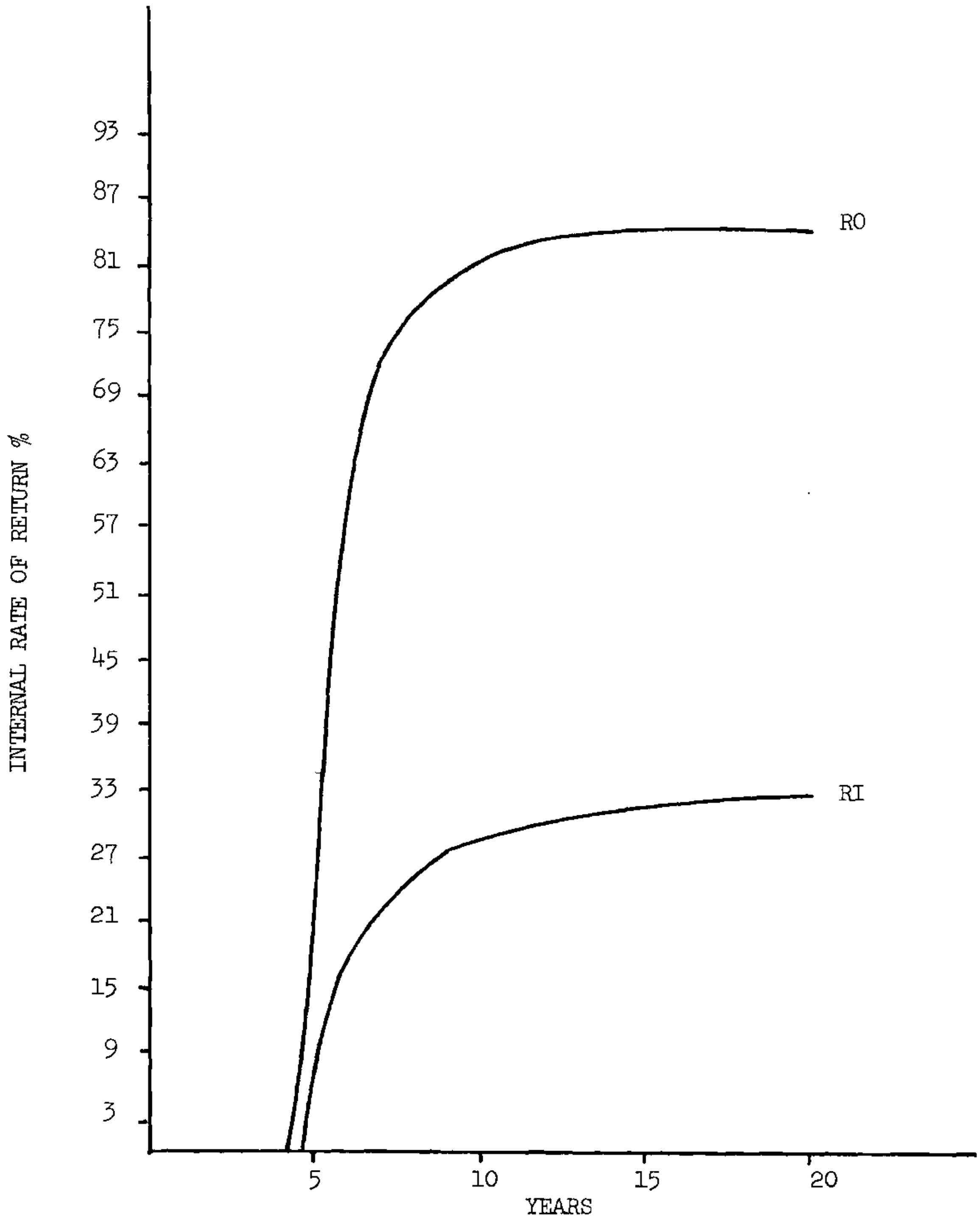

Figure 13. Length of Loans - Rate of Return Curves

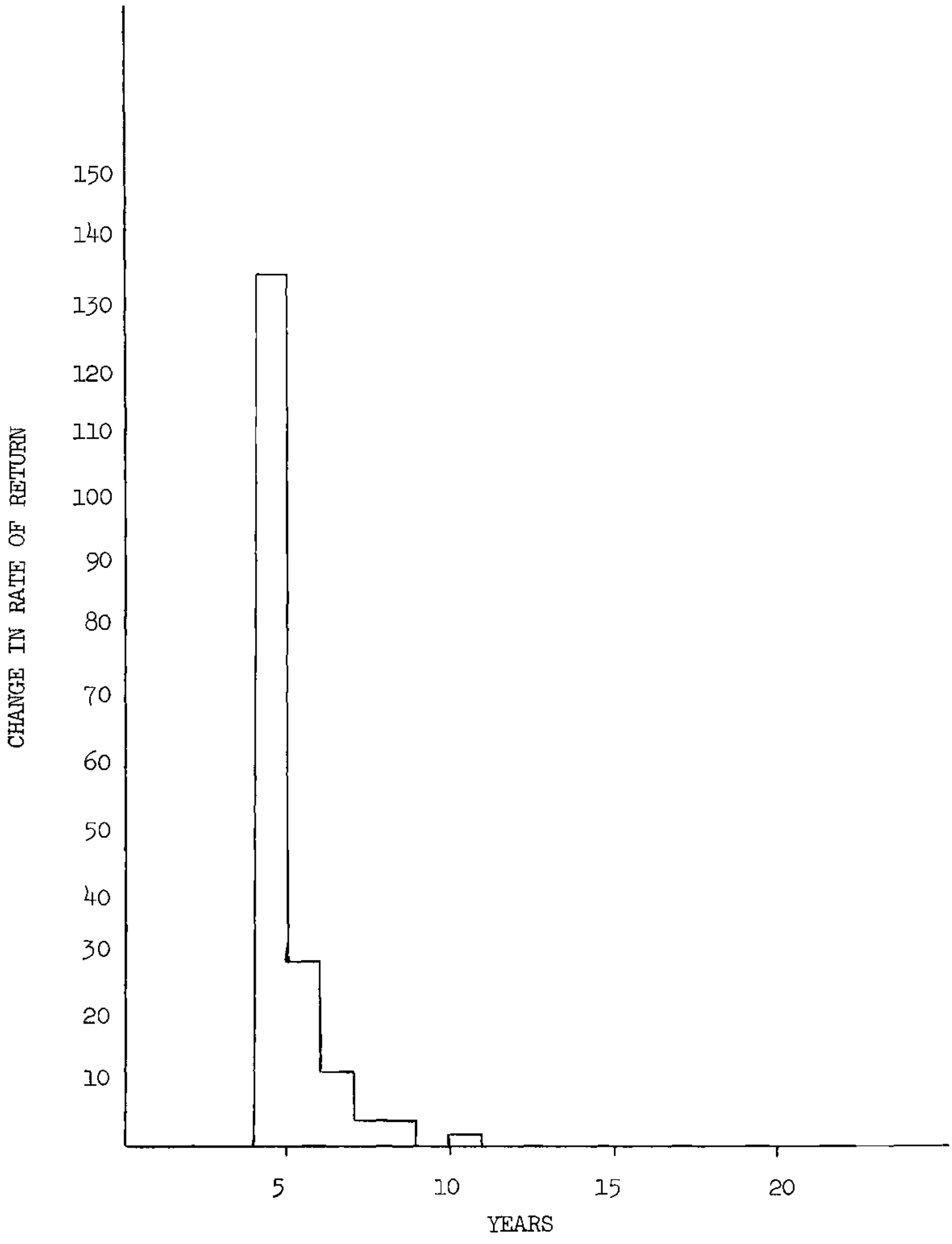

Figure 14. Length of Loans - Change in Rate of Return

CHAPTER VII

CONCLUSIONS AND OUTLOOK

Test Case

The four tests which were discussed in the previous chapter reveal information about ocean manganese nodule mining that could be useful to firms contemplating investments in this area. These tests indicate that the first years of production from the ocean deposit will be crucial to the economic worth of the investment. During these early years in the life of the project, tax allowances are available to reduce tax expenses and the time value of money is relatively close to face value. As the length of the project extends, however, tax allowances are depleted and the time value of money reduces the value of profits.

The shape of the rate of return curves in the figures of the previous chapter illustrate the importance of the first years of operation. The reasons for the sharp increase in the rate of return at the start of operations and its subsequent leveling off stage are the tax allowance structure and the nature of the discounting function. The losses which are sustained in the development years of the project can be used as tax allowances when profits are first generated. Tax expenses will thus be lower in the first years of operation. In addition, the discount factor for measuring the time value of money is close to one for the first few years of the project, but declines and approaches zero as the length of the project increases.

Another important economic condition which the tests of the previous chapter pointed out is the dependence of the economic worth on the prices of the minerals. When the market prices for the minerals in the model were reduced by 20 per cent, the economic worth of the investment decreased 26 per cent. Since the market prices for these and many other minerals can be a highly variable element, the risks which firms will have to take when they invest in ocean manganese mining will be high.

Figure 15 is a graph of the cash surpluses generated by the ocean manganese nodule project under reduced price conditions and under the conditions of the other tests of the previous chapter. The reduced price case produced the lowest level of cash surpluses of the five cases. This reemphasizes the importance of the price factor to the economic worth of the project.

The test which involved a 400 per cent increase in the mining vessel cost received the poorest ratings from the measures of economic worth, but the cash surpluses which are produced under the conditions of this test are actually greater than those of the reduced price case and the reduced production case. These higher cash surpluses require higher investments, however, and this reduces the economic desirability of the investment.

An analysis of the figures of the previous chapter and Figure 15 leads to the conclusion that there is an economic incentive for mining firms to invest capital in ocean manganese nodule mining. This conclusion is contingent on the assumptions that these firms can input capital under the conditions of this model and can achieve the cost levels estimated by this model. It is also contingent on the assumption that these firms are willing to take high risks.

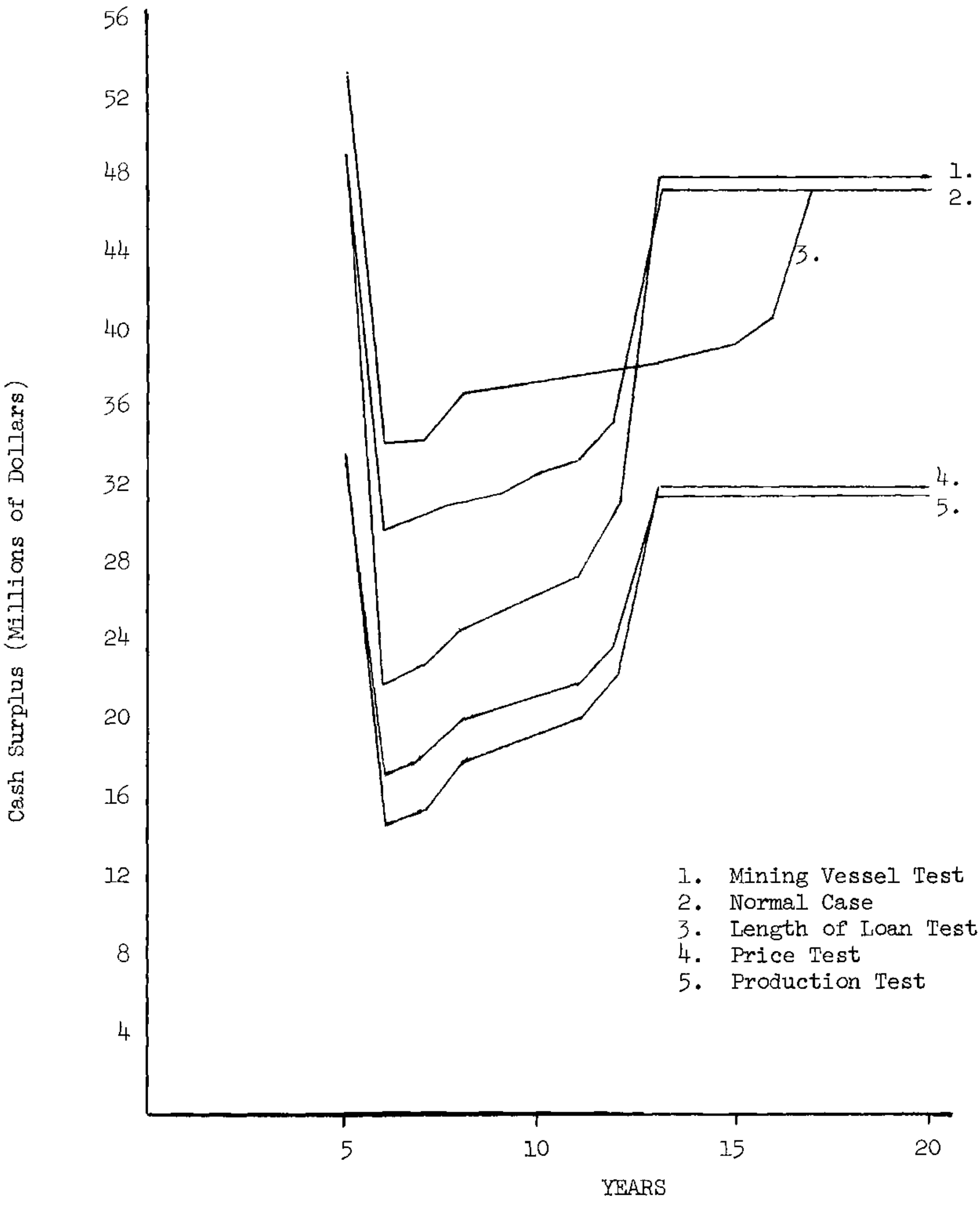

Figure 15. Cash Surplus

The type of mining systems which appear to be most suited to ocean manganese mining are those with high throughputs. Annual production rates of 1,500,000 tons of nodules or more seem to be needed to achieve the more favorable rates of return. Production rates under 1,000,000 tons of nodules per year would probably not produce rates of return large enough to justify the high risks involved.

The curves for the rate of return on total investment indicate that financing an ocean mining project of this nature may be difficult. The returns on total investment may not be sufficiently high, considering the high risk, to enable the firm to obtain loans.

General Ocean Mining Case

Ocean mining is presently in its developmental stage and very few tested systems are available. Firms entering this field must therefore create new systems. These new systems should have the advantage of modern technology and systems management, and hopefully would be void of many of the traditional inefficiencies common to older systems. The mineral resources which contained in the oceans are becoming increasingly important as land resources are depleted and new equipment is developed which makes ocean more practical. Recent developments in sea floor exploration equipment, for instance, have provided a nuclear instrument which can make analyses on the sea floor. As breakthroughs such as this are made in equipment capabilities, men will probably consider ocean deposits more and more as sources of minerals.

Another consideration which may hasten the use of the ocean's mineral resources is the current ecology movement. Man has suddenly realized that the rapid progress of past centuries has caused a deterioration of the natural environment. Land mining practices such as strip mining are now being criticized for their destruction of the land. These types of mining were used in the past because they were low cost methods of extracting the mineral ore from the deposit. Today, however, society may be unwilling to bear the destructive nature of these mining practices, and new techniques may have to be employed. These new techniques may require higher initial expenditures on the part of the mining firm, and thus, come closer to the costs of similar ocean deposits.

Also being criticized are the techniques which many firms use for waste disposal. The federal government is presently attacking this problem by setting pollution standards to which firms must abide. These measures mean additional costs for some firms and may even shut down others. If ocean systems can be designed which do not destroy or pollute the environment, they will have considerable qualitative advantages over many land based mining systems. The opposite case will be true, of course, if it can be proven that ocean mining systems cause unacceptable destruction of the environment. If man is to learn anything from past experience, the effects of mining the ocean floor should be extensively studied before any large scale ventures are started. The current trend of looking at the total system of a particular problem and determining the effects which changes in certain parts of the system produce in other parts should be employed in the case of ocean mining.

Another factor is presently discouraging the development of ocean deposits. This is the lack of laws and regulations pertaining to ocean deposits outside the territorial limits of costal states. Laws governing ownership and legal mining rights to many ocean deposits are very inadequate. Some nations, such as the United States, have claimed mineral rights for the continental shelves bordering them. A 200 meter depth is considered by some to be the cutoff point for ownership by the coastal state. No definite ruling, however, has been accepted for world wide use. This means that an ocean mining firm must take the risk that the deposit it is mining will not be claimed by someone else. The difficulty of establishing a ruling such as this is understandable, but this difficulty can only increase as knowledge concerning the location of valuable deposits is obtained.

The general outlook for undersea mining appears to be favorable, but rapid progress will probably not come for several years. If Deepsea Ventures, Inc., succeeds in its attempt to mine manganese nodules from the mid-Pacific, the door may open for the exploitation of many other ocean deposits.

APPENDIX A

COMPUTER MODEL

```
      DIMENSION T(25),EC(25),CM1(25),CT1(25),CP1(25),CM2(25),CT2(25),CP2
     1(25),DM(25),DT(25),DP(25),DX(25),DX1(25),EC1(25),EC2(25),TA(25),SU
     2(25),DEL(25),DRS(25),D(25),SPPW(84,25),TCP(25),TCU(25),PPT(25),PBT
     31(25),DAT(25),PEP(25),PEX(25),CP(25),CS(25),VST(30,30),CA(30),RI(2
     45),STD(25),TI(25),RO(25),CG(25),OWN(25),TOTI(25),CASH(25),O(25),T1
     5(25),TCT(25),BVA(25),TE(25),TFC(25)
      INTEGER SCM,SS,WRM
      REAL IC(25),IE(25),MAE(25),INS(25),NR(25),WC(25),WCB(25),LTB(25),M
     1L,MM,MS,M,MO,LA,INX,INV,LTP1(25),OW(25),WCB1(25),WCB2(25),WCB3(25)
     2,WCB4(25),BVA1(25),WCO(25)
 1000 FORMAT(7I5)
      READ(5,1000)SS,WRM,LD,NYB,NS,I1,I2
 1001 FORMAT(9F7.0)
      READ(5,1001)SM,CNM,DSM,CDT,S,DSTI,CNT1,CNT2,ST2
 1002 FORMAT(3F10.0)
      READ(5,1002)CM,DG,VM
 1003 FORMAT(5F6.3)
      READ(5,1003)G,XM,XN,XC,XH
 1004 FORMAT(4F6.0)
      READ(5,1004)PM,PN,PC,PB
      LP=5*LD
      LME=LP-LD+1
      LTE=LP-LD+1
      LPE=LP-LD+1
      VT=VM*(1-WRM)
      RTD=2*S/(SS*24)+4
      TPY=350/RTD
```

```
      NS1=VT/(TPY*CDT)
      NS2=NS1*G
      R1=VT/CDT
      CT=NS1*550000
      CP=(VT/1800000)**.6*60000000
      WPI=.1*CP
      DO 1 K=1,LP
      T(K)=0
      EC(K)=0
    1 CONTINUE
      T(LD-1)=8000000
      CF=5000000
      EC(1)=3000000
      EC(2)=3000000
      WM=6*VM
      LA=5*VT
      SCM=1.25*(13*(CNM/1000)**(1/6)+12*(SM/1000)**(1/5)-12)
      ML=SCM*15000
      MM=10000*(CNM/1000)**(2/3)+4500*(SM/1000)**(2/3)+.05*DG
      MS=80*(SCM/10)**4+.02*7200*SM
      VMN=VT*XMN*.05
      VM=VT*XM*.95
      VC=VT*XC*.95
      VB=VT*XB*.95
      GM=VMN*PM+VM*PM+VC*PC+VB*PB
      TM=(10000*(CNT1/1000)**(2/3)+40000)*NS1+10000*(CNT2/1000)**(2/3)
     1+4500*(ST2/1000)**(2/3)*NS2
      TL=15000*(NS1*9+NS2*13)
      TF=670*350*NS2+1000+80*(DST1/1000)*RT
      TM=(50000+12*(DST1/1000))*(NS1+NS2)+1500*350*NS2
      KM=LD
      KT=LD
      DO 3 K=1,LP
      CM1(K)=0
      CT1(K)=0
      CP1(K)=0
      WCB(K)=0
      WCC(K)=0
      WC(K)=0
      WCB1(K)=0
      WCB2(K)=0
      WCB3(K)=0
      WCB4(K)=0
      CM2(K)=0
      CT2(K)=0
      CP2(K)=0
      DM(K)=0
      DT(K)=0
      DP(K)=0
    3 CONTINUE
      CM2(0)=0
      CT2(0)=0
      CP2(0)=0
      EC1(0)=0
      EC2(0)=0
      TI(0)=0
      WCB(0)=0
```

```
          WCO(0)=0
          WCP1(0)=0
          WCP2(0)=0
          WCP3(0)=0
          WCP4(0)=0
          CM1(KM-1)=.1*CM
          CM1(KM)=.9*CM
          CT1(KT-1)=.1*CT
          CT1(KT)=.9*CT
          CP1(LD-1)=.1*(CP+WPI+CF)
          CP1(LD)=.9*(CP+WPI+CF)
          N1=NYD-1
          NM=KM+N1
          NT=KT+N1
          NP=LD+N1
          NE1=N1+1
          NE2=N1+2
          DO 4 K=KM,NM
          CM2(K)=.1*CM
          T1(K)=T(LD-1)
        4 CONTINUE
          LX=LD+N1
          DO 70 K=LD,LX
          CM2(K)=CM2(K)+.9*CM
       70 CONTINUE
          DO 5 K=KT,NT
          CT2(K)=.1*CT
        5 CONTINUE
          DO 71 K=LD,LX
          CT2(K)=CT2(K)+.9*CT
       71 CONTINUE
          DO 7 K=LD,NP
          CP2(K)=.1*(CP+WPI+CF)
        7 CONTINUE
          DO 73 K=LD,LX
          CP2(K)=.9*(CP+WPI+CF)+CP2(K)
       73 CONTINUE
          DO 9 K=1,NE1
          EC1(K)=EC(1)
        9 CONTINUE
          DO 11 K=2,NE2
          EC2(K)=EC(2)
       11 CONTINUE
          DO 13 K=KM,LP
          DM(K)=CM
       13 CONTINUE
          DO 15 K=KT,LP
          DT(K)=CT
       15 CONTINUE
          DO 17 K=LD,LP
          DP(K)=CP+WPI+CF
       17 CONTINUE
          DO 19 K=1,LP
          DX(K)=.7*(EC(K)+T(K))
          MAE(K)=.3*(EC(K)+T(K))
       19 CONTINUE
          DO 21 K=1,LP
```

```
      TA(K)=CM1(K)+CT1(K)+CP1(K)+.7*(EC(K)+T(K))
   21 CONTINUE
      WC(1)=TA(1)
      WCB(1)=(.667)*WC(1)
      WCO(1)=WC(1)-WCB(1)
      WC(2)=TA(2)
      WCB(2)=(.667)*WC(2)
      WCO(2)=WC(2)-WCB(2)
      WC(3)=.333*TA(3)
      WCB(3)=(.667)*WC(3)
      WCO(3)=WC(3)-WCB(3)
      WC(4)=.25*TA(4)
      WCB(4)=(.750)*WC(4)
      WCO(4)=WC(4)-WCB(4)
      DO 60 K=1,NE1
      WCB1(K)=WCB(1)
   60 CONTINUE
      DO 61 K=2,NE2
      WCB2(K)=WCB(2)
   61 CONTINUE
      KX=3+NYB-1
      DO 62 K=3,KX
      WCB3(K)=WCB(3)
   62 CONTINUE
      DO 63 K=4,NP
      WCB4(K)=WCB(4)
   63 CONTINUE
      LC=LD+1
      DO 22 K=LC,LP
      WC(K)=0
      WCB(K)=0
   22 CONTINUE
      OCM=ML+MM+MS
      OCT=TM+TL+TF
      OCP=15*VT
      PO=(.111)*OCP
      WPA=1*VT
      M=(.25)*(OCP+PO)
      MO=(.111)*OCM
      DO 23 K=1,LP
      SU(K)=0
   23 CONTINUE
      SU(LD)=.25*(ML+TL+.3*OCP+.5*M)+.1*(OCM+OCT+OCP)
      DO 25 K=1,LP
      IC(K)=.1*(EC(K)+T(K)+CM1(K)+CT1(K)+CP1(K)+SU(K))
   25 CONTINUE
      LZ=LD-1
      DRE(0)=0
      CASH(0)=0
      WC(0)=0
      CD(0)=0
      LTR(0)=0
      OW(0)=0
      TOT(0)=0
      BVA(0)=0
      DX1(0)=0
      QA(0)=0
```

```
      PLP(0)=0
      PEX(0)=0
      STM(0)=0
      OWN(0)=0
      TOTI(0)=0
      DO 28 L=1,LP
      IF(L-LP)8,10,10
    8 LTB1(L)=.667*TA(L)+WCB(L)
      LTB(L)=LTB(L-1)+LTB1(L)-DRL(L-1)
      GO TO 12
   10 LTB1(L)=.750*TA(L)+WCB(L)
      LTB(L)=LTB(L-1)+LTB1(L)-DRL(L-1)
   12 NXB=L+(NYB-1)
      DO 27 K=1,L
      QA(K)=0
   27 CONTINUE
      DO 6 K=L,NXB
      WST(K,L)=LTB1(L-1)/NYB
    6 CONTINUE
      NSX=L-(NYB-1)
      IF(NSX)52,52,53
   52 NSX=1
   53 DO 54 N=NSX,L
      QA(N)=WST(L,N)+QA(N-1)
   54 CONTINUE
      DRL(L)=QA(L)
   28 CONTINUE
      LPY=LP+1
      DO 29 K=1,LP
      DX1(K)=DX(K)/(LPY-K)+DX1(K-1)
      D(K)=DM(K)/LME+DT(K)/LTE+DP(K)/LPE+DX1(K)
      INX=DM(K)*.03*(LME+1)/(2*LME)+DT(K)*.03*(LTE+1)/(2*LTE)
      INV=DP(K)*.03*(LPE+1)/(2*LPE)
      INS(K)=INX+INV
      NR(K)=CR-INS(K)-M-LA
      BVA(K)=TA(K)-D(K)+BVA(K-1)
      TA(K)=CM1(K)+CT1(K)+CP1(K)+.7*(EC(K)+T(K))
   29 CONTINUE
      DO 14 K=1,LP
      DO 16 IR=1,80
      SPPW(IR,K)=1/(1+(IR-20)*.02)**K
   16 CONTINUE
   14 CONTINUE
      DRS(0)=0
      TCD(0)=0
      DO 31 J=1,LP
      NSQ=J+(NS-1)
      DO 33 K=1,J
      QA(K)=0
   33 CONTINUE
      DO 35 K=J,NSQ
      WST(K,J)=STB(J-1)/NS
   35 CONTINUE
      NSR=J-(NS-1)
      IF(NSR)40,40,47
   40 NSR=1
   47 DO 49 N=NSR,J
```

```
      QA(N)=WST(J,N)+QA(N-1)
   49 CONTINUE
      DRS(J)=QA(J)
      DO 51 K=1,J
      PEP(K)=STB(K-1)+PEP(K-1)
      PEX(K)=DRS(K-1)+PEX(K-1)
   51 CONTINUE
      IC(J)=(PEP(J)-PEX(J))*I1*.01+LTB(J)*I2*.01
      IF(LD-J)200,100,100
  100 PBT(J)=-(INS(J)+IE(J)+MAE(J)+D(J)+SU(J)+IC(J))
      NR(J)=0
      PBT1(J)=PBT(J)
      TE(J)=0
      PAT(J)=PBT(J)-TE(J)
      CG(J)=PAT(J)+D(J)
      CD(J)=-(CG(J)-DRL(J)-DRS(J))
      CS(J)=0
      TCD(J)=TCD(J-1)-PBT1(J)
      TCC(J)=0
      IF(LD-J)119,119,120
  119 O(J)=.25*TA(J)+WCO(J)
      GO TO 124
  120 O(J)=.333*TA(J)+WCO(J)
  124 CCX=WC(J)-CD(J)
      IF(CCX)121,121,122
  121 STB(J)=-CCX
      GO TO 123
  122 WC(J+1)=WC(J+1)+CCX
      STB(J)=0
      GO TO 123
  123 TI(J)=O(J)+LTB1(J)+STB(J)-DRL(J)-DRS(J)
      RC(J)=0
      RI(J)=0
      GO TO 31
  200 PBT(J)=NR(J)-(OCM+WM+MO+OCT+TH+OCP+PO+WPA+D(J)+IE(J))
      IF(PBT(J))210,210,270
  210 PBT1(J)=PBT(J)
      TE(J)=0
      PAT(J)=PBT(J)-TE(J)
      CG(J)=PAT(J)+D(J)+WC(J)
      TE(J)=0
      TCD(J)=TCD(J-1)-PBT1(J)
      IF(CG(J))220,220,240
  220 CD(J)=-(CG(J)-DRL(J)-DRS(J))
      CS(J)=0
  230 O(J)=.250*TA(J)+WCO(J)
      STB(J)=CD(J)
      TI(J)=O(J)+LTB1(J)+STB(J)-DRL(J)-DRS(J)
      GO TO 400
  240 CC=CG(J)-DRL(J)-DRS(J)
      IF(CC)220,220,250
  250 CS(J)=CC
      CD(J)=0
  260 O(J)=.250*TA(J)+WCO(J)
      STB(J)=0
      TI(J)=O(J)+LTB1(J)+STB(J)-DRL(J)-DRS(J)
      GO TO 400
```

```
  270 IF(TCD(J-1)-PBT(J))290,290,310
  290 PBT1(J)=PBT(J)-TCD(J-1)
      TE(J)=.50*PBT1(J)
      TCD(J)=0
      TCU(J)=TCD(J-1)
      PAT(J)=PBT(J)-TE(J)
      CG(J)=PAT(J)+D(J)+WC(J)
      CC=CG(J)-DRL(J)-DRS(J)
      IF(CC)295,295,300
  295 CD(J)=-CC
      CS(J)=0
      GO TO 230
  300 CS(J)=CC
      CD(J)=0
      GO TO 260
  310 PBT1(J)=0
      TE(J)=0
      PAT(J)=PBT(J)-TE(J)
      TCU(J)=PBT(J)
      TCD(J)=TCD(J-1)-TCU(J)
      CG(J)=PAT(J)+D(J)+WC(J)
      CC=CG(J)-DRL(J)-DRS(J)
      IF(CC)295,295,300
  400 DO 401 K=1,J
      OW(K)=O(K)+OW(K-1)
      TOTI(K)=TI(K)+TOTI(K-1)
      CASH(K)=CS(K)+CASH(K-1)
  401 CONTINUE
      IR=((CASH(J)/OW(J))-1.000)*50+20
      IF(IR-70)404,404,407
  407 IR=80
  404 IB=((CASH(J)+BVA(J))/TOTI(J)-1.000)*50+20
      IF(IB-70)406,406,405
  405 IB=80
  406 IF(J-LC)31,410,410
  410 DO 403 K=1,J
      CASH(K)=CS(K)*SPPW(IR,K)+CASH(K-1)
      OWN(K)=O(K)*SPPW(IR,K)+OWN(K-1)
  403 CONTINUE
      IF(CASH(J)-OWN(J))412,416,418
  412 IR=IR-1
      GO TO 410
  416 RO(J)=(IR-20)*2
      GO TO 430
  418 RO(J)=((IR-20+IR-20+1)/2)*2
      GO TO 430
  430 DO 432 K=1,J
      CASH(K)=CS(K)*SPPW(IB,K)+CASH(K-1)
      BVAI(K)=BVA(K)*SPPW(IB,K)
      TOT(K)=TI(K)*SPPW(IB,K)+TOT(K-1)
  432 CONTINUE
      CASH(J)=CASH(J)+BVAI(J)
      IF(CASH(J)-TOT(J))434,436,438
  434 IB=IB-1
      GO TO 430
  438 RI(J)=(IB-20)*2
      GO TO 31
```

```
  438 RI(J)=((IB-20+IB-20+1)/2)*2
      GO TO 31
   31 CONTINUE
      DO 408 K=1,LP
      TWC(K)=SU(K)+IC(K)+MAE(K)
  408 CONTINUE
      L=1
      L2=2
      L3=3
      L4=4
      LL=5
  499 GO=GO
 1049 FORMAT(1H1)
      WRITE(6,1049)
 1050 FORMAT(//,8H ELEMENT,3X,I2,9X,I2,9X,I2,9X,I2,9X,I2,//)
      WRITE(6,1050)L,L2,L3,L4,LL
 1052 FORMAT(3H TA,3X,5F11.0)
      WRITE(6,1052)(TA(J),J=L,LL)
 1053 FORMAT(3H WC,3X,5F11.0)
      WRITE(6,1053)(WC(J),J=L,LL)
 1055 FORMAT(2H O,4X,5F11.0)
      WRITE(6,1055)(O(J),J=L,LL)
 1057 FORMAT(5H LTBI,1X,5F11.0)
      WRITE(6,1057)(LTBI(J),J=L,LL)
 1059 FORMAT(3H TI,3X,5F11.0)
      WRITE(6,1059)(TI(J),J=L,LL)
 1054 FORMAT(3H OW,3X,5F11.0)
      WRITE(6,1054)(OW(J),J=L,LL)
 1056 FORMAT(4H LTB,2X,5F11.0)
      WRITE(6,1056)(LTB(J),J=L,LL)
 1058 FORMAT(5H TOTI,1X,5F11.0)
      WRITE(6,1058)(TOTI(J),J=L,LL)
 1060 FORMAT(4H STB,2X,5F11.0)
      WRITE(6,1060)(STB(J),J=L,LL)
 1061 FORMAT(4H BVA,2X,5F11.0)
      WRITE(6,1061)(BVA(J),J=L,LL)
 1062 FORMAT(1X,2HVT,47X,F11.0)
      WRITE(6,1062)VT
 1064 FORMAT(3H GP,47X,F11.0)
      WRITE(6,1064)GP
 1066 FORMAT(4H INS,2X,5F11.0)
      WRITE(6,1066)(INS(J),J=L,LL)
 1068 FORMAT(2H M,48X,F11.0)
      WRITE(6,1068)M
 1069 FORMAT(3H LA,47X,F11.0)
      WRITE(6,1069)LA
 1070 FORMAT(3H NR,3X,5F11.0)
      WRITE(6,1070)(NR(J),J=L,LL)
 1071 FORMAT(4H OCM,46X,F11.0)
      WRITE(6,1071)OCM
 1072 FORMAT(3H MC,47X,F11.0)
      WRITE(6,1072)MC
 1073 FORMAT(4H OCT,46X,F11.0)
      WRITE(6,1073)OCT
 1074 FORMAT(3H TH,47X,F11.0)
      WRITE(6,1074)TH
 1075 FORMAT(4H OCP,46X,F11.0)
```

```
            WRITE(6,1075)OCF
      1076  FORMAT(3H Po,47X,F11.0)
            WRITE(6,1076)Po
      1077  FORMAT(4H WPA,46X,F11.0)
            WRITE(6,1077)WPA
      1078  FORMAT(2H D,4X,5F11.0)
            WRITE(6,1078)(D(J),J=L,LL)
      1079  FORMAT(4H TMC,2X,5F11.0)
            WRITE(6,1079)(TMC(J),J=L,LL)
      1080  FORMAT(3H IE,3X,5F11.0)
            WRITE(6,1080)(IE(J),J=L,LL)
      1082  FORMAT(4H PBT,2X,5F11.0)
            WRITE(6,1082)(PBT(J),J=L,LL)
      1084  FORMAT(4H TCD,2X,5F11.0)
            WRITE(6,1084)(TCD(J),J=L,LL)
      1086  FORMAT(5H PBT1,1X,5F11.0)
            WRITE(6,1086)(PBT1(J),J=L,LL)
      1088  FORMAT(3H TE,3X,5F11.0)
            WRITE(6,1088)(TE(J),J=L,LL)
      1090  FORMAT(4H PAT,2X,5F11.0)
            WRITE(6,1090)(PAT(J),J=L,LL)
      1091  FORMAT(2H D,4X,5F11.0)
            WRITE(6,1091)(D(J),J=L,LL)
      1093  FORMAT(3H CG,3X,5F11.0)
            WRITE(6,1093)(CG(J),J=L,LL)
      1094  FORMAT(4H DRL,2X,5F11.0)
            WRITE(6,1094)(DRL(J),J=L,LL)
      1095  FORMAT(4H DRS,2X,5F11.0)
            WRITE(6,1095)(DRS(J),J=L,LL)
      1096  FORMAT(3H CS,3X,5F11.0)
            WRITE(6,1096)(CS(J),J=L,LL)
      1099  FORMAT(3H CD,3X,5F11.0)
            WRITE(6,1099)(CD(J),J=L,LL)
            WRITE(6,1053)(WC(J),J=L,LL)
      1097  FORMAT(3H RC,3X,5F11.3)
            WRITE(6,1097)(RC(J),J=L,LL)
      1098  FORMAT(3H RI,3X,5F11.3)
            WRITE(6,1098)(RI(J),J=L,LL)
            L=L+5
            L2=L2+5
            L3=L3+5
            L4=L4+5
            LL=LL+5
            IF(LL-20)499,499,500
       500  STOP
            END

END OF COMPILATION:          NO  DIAGNOSTICS.
```

```
STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001   001516 7VLG      0000 R 006712 BVA       0000 R 007576 BVA1
0000 R 007775 CCX       0000 R 004343 CD        0000 R 007670 CDT
0000 R 007676 CF        0000 R 000062 CM1       0000 R 000175 CM2
0000 R 007674 CNT2      0000 R 007725 CP        0000 R 000144 CP1
0000 R 007724 CT        0000 R 000113 CT1       0000 R 000226 CT2
0000 R 000372 DP        0000 R 007677 DG        0000 R 000651 DPL

0000 R 010056 DST1      0000 R 000341 DT        0000 R 000423 DX
0000 R 000565 EC1       0000 R 000536 EC2       0000 R 010665 G
0000 I 010763 IB        0000 R 010045 IE        0000 R 010127 INS
0000 R 010014 IO        0000 I 010755 IP        0000 I 010647 I1
0000 I 010713 K         0000 I 010727 KM        0000 I 010730 KT
0000 R 010331 LA        0000 I 010741 LC        0000 I 010644 LD
0000 I 010676 LP        0000 I 010701 LPE       0000 I 010754 LPX
0000 I 010700 LTE       0000 I 010737 LX        0000 I 010747 LZ
0000 I 010766 L4        0000 R 010327 M         0000 R 010076 MAE
0000 R 010330 MO        0000 R 010326 MS        0000 I 010753 N
0000 I 010732 NM        0000 I 010734 NP        0000 R 010160 NR
0000 I 010760 NSR       0000 I 010752 NSX       0000 I 010705 NS1
0000 I 010751 NXG       0000 I 010645 NYB       0000 I 010731 N1
0000 R 010744 OCP       0000 R 010743 OCT       0000 R 010765 OW
0000 R 010675 PL        0000 R 005132 PBT       0000 R 005163 PBT1
0000 R 005276 PEX       0000 R 010672 PM        0000 R 010673 PN
0000 R 007253 RI        0000 R 007366 RO        0000 R 010707 RT
0000 I 010011 SCM       0000 R 010651 SM        0000 R 000764 SPPW
0000 R 010661 ST2       0000 R 000620 SU        0000 R 000000 T
0000 R 005101 TCU       0000 R 007727 TE        0000 R 010725 TF
0000 R 010724 TL        0000 R 010723 TM        0000 R 007760 TMC
0000 R 010704 TPY       0000 R 007614 T1        0000 R 010721 VB
0000 R 010716 VMN       0000 R 010717 VN        0000 R 010702 VT
0000 R 010416 WCB1      0000 R 010447 WCB2      0000 R 010500 WCB3
0000 R 010715 WR        0000 R 010746 WPA       0000 R 010712 WPI
0000 R 010071 XS        0000 R 010670 XC        0000 R 010666 XM

0000 R 000454 DX1       0000 P 000031 EC        0000 R 006546 CASH
0000 R 010770 GC        0000 R 010722 GP        0000 R 007730 CF
0000 R 010333 INV       0000 R 010332 INX       0000 R 007666 CCM
0000 I 010650 I2        0000 I 010756 J         0000 R 000257 CP2
0000 I 010740 KX        0000 I 010750 L         0000 R 000733 D
0000 I 010767 LL        0000 I 010677 LME       0000 R 000702 DPS
0000 R 010273 LTB       0000 R 010334 LTB1      0000 R 007776 CC
0000 I 010764 L2        0000 I 010765 L3        0000 R 006433 CG
0000 R 010324 ML        0000 R 010325 MV        0000 R 007673 CNT1
0000 I 010735 NE1       0000 I 010736 NE2       0000 R 004374 CS
0000 I 010646 NS        0000 I 010757 NSQ       0000 R 000310 DM
0000 I 010706 NS2       0000 I 010733 NT        0000 R 007667 DSM
0000 R 007563 O         0000 R 010742 OCM
0000 R 007450 OWN       0000 R 005214 PAT
0000 R 010674 PC        0000 R 005245 PCP
0000 R 010745 PD        0000 R 007215 QA
0000 R 010703 PTD       0000 R 010655 S
0000 I 010012 SS        0000 R 007304 STB
0000 R 000567 TA        0000 R 005050 TCD
0000 R 010726 TH        0000 R 007335 TI
0000 R 007645 TOT       0000 R 007501 TOTI
0000 R 010720 VC        0000 R 010664 VM
0000 R 010211 WC        0000 R 010242 WCB
0000 R 010531 WCB4      0000 R 010613 WCO
0000 I 010013 WPM       0000 R 005411 WST
0000 R 010667 XN
```

APPENDIX B

OUTPUT FOR TESTS

ELEMENT	1	2	3	4	5
TF	2100000.	2100000.	14546095.	86514859.	0.
WC	2100000.	2775888.	5621339.	20128715.	0.
C	1398600.	1398600.	6456852.	25160853.	0.
LT 1	2801400.	2801400.	12033093.	75482680.	0.
TI	4200000.	3849825.	19318073.	104765610.	-14177986.
OW	1398600.	2797200.	9054052.	34414945.	34414945.
LT	2801400.	5602800.	18185718.	92968048.	90651062.
TOTI	4200000.	8049825.	27767898.	132133508.	117955522.
ST	0.	0.	628478.	6648515.	0.
BV	1995000.	5679474.	17698932.	92624744.	86935698.
VT					1500000.
G					151471798.
INS	0.	0.	0.	1420850.	1420850.
F					6249375.
LA					7500000.
NR	0.	0.	0.	0.	136301574.
OC					2883580.
MO					320077.
OCF					7923000.
TH					10005376.
CCP					22500000.
PO					2497500.
WPA					1500000.
D	105000.	215526.	526637.	5789046.	5789046.
TMC	1200000.	1200000.	4094609.	15354748.	0.
IE	224112.	498224.	1454857.	7475152.	7676135.
PBT	-1529112.	-1863750.	-6076104.	-30039798.	75206862.
TCD	1529112.	3392862.	9468966.	39508764.	0.
PBT1	-1529112.	-1863750.	-6076104.	-30039798.	35698098.
TE	0.	0.	0.	0.	17949049.
PAT	-1529112.	-1863750.	-6076104.	-30039798.	57357813.
D	105000.	215526.	526637.	5789046.	5789046.
CG	-1424112.	-1648224.	-5549467.	-24250751.	63146859.
DRL	0.	350175.	700350.	2316987.	11752322.
DRS	0.	0.	0.	209493.	2425664.
CS	0.	0.	0.	0.	48968873.
CD	1424112.	1998399.	6249817.	26777230.	0.
WC	2100000.	2775888.	5621339.	20128715.	0.
RO	.000	.000	.000	.000	26.000
RI	.000	.000	.000	.000	10.000

ELEMENT	6	7	8	9	10
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTL1	0.	0.	0.	0.	0.
TI	-14177986.	-13968493.	-11752322.	-11752322.	-11402147.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTL	78858781.	67146420.	55394099.	43641777.	31889456.
TOTI	103777536.	[illegible]9043.	78056722.	66304401.	54902254.
STF	0.	0.	0.	0.	0.
HVA	81046652.	75237606.	69468960.	63679514.	57890467.
VT					1500000.
GR					15147179?.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	136301574.	136301574.	136301574.	136301574.	136301574.
OCM					2883580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TAC	0.	0.	0.	0.	0.
IE	6590469.	5504684.	4431528.	3491342.	2551156.
PBT	76292586.	77378312.	78451468.	79391654.	80331840.
TCD	0.	0.	0.	0.	0.
PBTI	76292586.	77378312.	78451468.	79391654.	80331840.
TE	38146293.	38689156.	39225734.	39695827.	40165920.
PAT	38146293.	38689156.	39225734.	39695827.	40165920.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	43935339.	44478202.	45014780.	45484873.	45954966.
DRL	11752322.	11752322.	11752322.	11752322.	11402147.
DRS	2425664.	2216172.	0.	0.	0.
CS	29757353.	30509709.	33262459.	33732552.	34552820.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	54.000	66.000	72.000	76.000	76.000
RI	18.000	22.000	26.000	28.000	28.000

ELEMENT	11	12	13	14	15
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LT 1	0.	0.	0.	0.	0.
TI	-11051972.	-9435335.	0.	0.	0.
OA	34414945.	34414945.	34414945.	34414945.	34414945.
LT	20467359.	9435338.	3.	3.	3.
TOT1	43650283.	34414948.	34414948.	34414948.	34414948.
ST	0.	0.	0.	0.	0.
BVA	52101401.	46312374.	40523328.	34734281.	28945235.
VI					1500000.
GR					15147179.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
N					6249375.
LA					7500000.
MR	136301574.	136301574.	136301574.	136301574.	136301574.
OCM					2283580.
MC					320077.
OC1					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IC	1068985.	754827.	0.	0.	0.
PST	81244012.	82128168.	82882996.	82882996.	82882996.
TCD	0.	0.	0.	0.	0.
PST1	81244012.	82128168.	82882996.	82882996.	82882996.
TE	40622006.	41064084.	41441498.	41441498.	41441498.
PAT	40622006.	41064084.	41441498.	41441498.	41441498.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	46411052.	46853130.	47230544.	47230544.	47230544.
DRL	11051972.	9435335.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	35359081.	37417795.	47230544.	47230544.	47230544.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	78.000	78.000	78.000	78.000	78.000
RI	30.000	30.000	30.000	32.000	32.000

ELEMENT	16	17	18	19	20
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LIN1	0.	0.	0.	0.	0.
TI	0.	0.	0.	0.	0.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTD	3.	3.	3.	3.	3.
TOTI	34414948.	34414948.	34414948.	34414948.	34414948.
STO	0.	0.	0.	0.	0.
BVA	23156188.	17367142.	11578095.	5789049.	0.
VT					1500000.
GR					151471798.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	136301574.	136301574.	136301574.	136301574.	136301574.
OC					2283580.
MO					320077.
OCI					7223000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IC	0.	0.	0.	0.	0.
PMI	82882996.	82882996.	82882996.	82882996.	82882996.
TCS	0.	0.	0.	0.	0.
PBTI	82882996.	82882996.	82882996.	82882996.	82882996.
TE	41441498.	41441498.	41441498.	41441498.	41441498.
PAT	41441498.	41441498.	41441498.	41441498.	41441498.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	47230544.	47230544.	47230544.	47230544.	47230544.
DRL	0.	0.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	47230544.	47230544.	47230544.	47230544.	47230544.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	78.000	78.000	78.000	78.000	78.000
RI	32.000	32.000	32.000	32.000	32.000

ELEMENT	1	2	3	4	5
TA	2100000.	2100000.	14546695.	80514859.	0.
WC	2100000.	2775888.	5621339.	20128715.	0.
C	1398600.	1398600.	6456852.	25160893.	0.
LG1	2801400.	2801400.	12933093.	75482660.	0.
T1	4200000.	3849820.	19318073.	104765610.	-14177986.
OA	1398600.	2777200.	9254652.	34414945.	34414945.
LT	2801400.	5602800.	18185718.	92968048.	90651062.
TOT1	4200000.	8049820.	27367898.	132133508.	117955522.
ST	0.	0.	628678.	6648515.	0.
BVA	1995000.	3879474.	17398932.	92624744.	86235692.
VT					1500000.
GR					121906724.
ING	0.	0.	0.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	0.	0.	0.	0.	105936500.
OCL					2983580.
MO					320077.
OCT					7923000.
TM					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	105000.	215520.	526637.	5789046.	5789046.
TMC	1200000.	1200000.	4094609.	15354748.	0.
IE	224112.	448224.	1454857.	7475152.	7676135.
PBT	-1529112.	-1863750.	-6076104.	-30039798.	44741787.
TCD	1529112.	3392862.	9468966.	39508764.	0.
PBT1	-1529112.	-1863750.	-6076104.	-30039798.	5233023.
TE	0.	0.	0.	0.	2616511.
PAT	-1529112.	-1863750.	-6076104.	-30039798.	42125275.
D	105000.	215520.	526637.	5789046.	5789046.
CG	-1424112.	-1648224.	-5549467.	-24250751.	47914322.
DRL	0.	350175.	700350.	2316987.	11752322.
DRS	0.	0.	0.	209493.	2425664.
CS	0.	0.	0.	0.	33736336.
CD	1424112.	1998399.	6049817.	26777230.	0.
WC	2100000.	2775888.	5621339.	20128715.	0.
RO	.000	.000	.000	.000	.000
R1	.000	.000	.000	.000	.000

ELEMENT	6	7	8	9	10
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTM1	0.	0.	0.	0.	0.
TI	-14177986.	-13968493.	-11752322.	-11752322.	-11402147.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTM	78898781.	67146420.	55394099.	43641777.	31889456.
TOTI	103777566.	89659043.	78056722.	66304401.	54902254.
STD	0.	0.	0.	0.	0.
BVA	81046652.	75257606.	69468560.	63679514.	57890467.
VT					1500000.
GR					121006724.
IRS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	105836500.	105836500.	105836500.	105836500.	105836500.
OCM					2883580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PU					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IE	6590469.	5504684.	4431528.	3491342.	2551156.
PBT	45827512.	46913238.	47986394.	48926579.	49866765.
TCD	0.	0.	0.	0.	0.
PBT1	45827512.	46913238.	47986394.	48926579.	49866765.
TE	22913756.	23456619.	23993197.	24463289.	24933382.
PAT	22913756.	23456619.	23993197.	24463289.	24933382.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	28702802.	29245665.	29782243.	30252336.	30722429.
DRL	11752322.	11752322.	11752322.	11752322.	11402147.
DRS	2425664.	2216172.	0.	0.	0.
CS	14524816.	15277172.	18029922.	18500014.	19320282.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	20.000	32.000	40.000	44.000	48.000
RI	8.000	12.000	14.000	16.000	18.000

ELEMENT	11	12	13	14	15
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LF-1	0.	0.	0.	0.	0.
TI	-11051972.	-9435335.	0.	0.	0.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LT	20467379.	9435338.	3.	3.	3.
TOTI	43850283.	34414948.	34414948.	34414948.	34414948.
ST	0.	0.	0.	0.	0.
BV	52101420.	46312374.	40523328.	34734281.	28945235.
VT					1500000.
GR					121906724.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	105836500.	105836500.	105836500.	105836500.	105836500.
OCI					2983580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IE	1638975.	754827.	0.	0.	0.
PBT	50778937.	51663094.	52417921.	52417921.	52417921.
TCL	0.	0.	0.	0.	0.
PBT1	50778937.	51663094.	52417921.	52417921.	52417921.
TE	25369468.	25831547.	26208960.	26208960.	26208960.
PAT	25369468.	25831547.	26208960.	26208960.	26208960.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	31178515.	31620593.	31998007.	31998007.	31998007.
DRL	11051972.	9435335.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	20126543.	22185258.	31998007.	31998007.	31998007.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	48.000	50.000	50.000	52.000	52.000
RI	18.000	18.000	20.000	20.000	20.000

ELEMENT	16	17	18	19	20
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTM1	0.	0.	0.	0.	0.
TI	0.	0.	0.	0.	0.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTM	3.	3.	3.	3.	3.
TOTI	34414948.	34414948.	34414948.	34414948.	34414948.
STM	0.	0.	0.	0.	0.
BVA	23156188.	17367142.	11578095.	5789049.	3.
VT					1500000.
GR					121006724.
ING	1420850.	1420850.	1420850.	1420850.	1420850.
M					6049375.
LA					7500000.
NR	105836500.	105836500.	105836500.	105836500.	105836500.
OCH					2493580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IC	0.	0.	0.	0.	0.
PBT	52417921.	52417921.	52417921.	52417921.	52417921.
TCD	0.	0.	0.	0.	0.
PBTI	52417921.	52417921.	52417921.	52417921.	52417921.
TE	26208960.	26208960.	26208960.	26208960.	26208960.
PAT	26208960.	26208960.	26208960.	26208960.	26208960.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	31998007.	31998007.	31998007.	31998007.	31998007.
DRL	0.	0.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	31998007.	31998007.	31998007.	31998007.	31998007.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	52.000	52.000	52.000	52.000	52.000
RI	20.000	22.000	22.000	22.000	22.000

ELEMENT	1	2	3	4	5
TA	2100000.	2100000.	12038530.	66046774.	0.
WC	2100000.	2775888.	5086020.	16511693.	0.
O	1398600.	1398600.	5743271.	20639617.	0.
LTM1	2801400.	2801400.	11503790.	61918850.	0.
TI	4200000.	3849825.	17435407.	85034030.	-11811118.
OW	1398600.	2797200.	8540471.	29180088.	29180088.
LTM	2801400.	5602800.	16756414.	77974915.	75836592.
TOTI	4200000.	8049825.	25085232.	110519262.	98708141.
STL	0.	0.	888697.	4910118.	0.
BVA	1995000.	3870474.	16291767.	77494720.	72651300.
VT					1000000.
GR					100981192.
INS	0.	0.	0.	1165531.	1165531.
M					4166250.
LA					5000000.
NR	0.	0.	0.	0.	90649419.
OCA					2883580.
MC					320077.
OCT					4963000.
TH					6253360.
OCP					15000000.
PC					1665000.
WPA					1000000.
D	165000.	215520.	526637.	4843420.	4843420.
TMC	1200000.	1200000.	3933857.	11530410.	0.
IE	224112.	448224.	1340513.	6291315.	6307082.
PGI	-1529112.	-1863750.	-5801004.	-23830676.	47323900.
TCL	1529112.	3392862.	9193966.	33024542.	0.
PGII	-1529112.	-1863750.	-5801004.	-23830676.	14299358.
TE	0.	0.	0.	0.	7149679.
PAT	-1529112.	-1863750.	-5801004.	-23830676.	40174221.
D	165000.	215520.	526637.	4843420.	4843420.
CG	-1424112.	-1648224.	-5274366.	-18987256.	45017641.
DRL	0.	300175.	700350.	2138324.	9878180.
DRS	0.	0.	0.	296232.	1932938.
CS	0.	0.	0.	0.	33206523.
CO	1424112.	1998399.	5074716.	21421812.	0.
WC	2100000.	2775888.	5086020.	16511693.	0.
RO	.000	.000	.000	.000	8.000
RI	.000	.000	.000	.000	4.000

ELEMENT	6	7	8	9	10
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LIB1	0.	0.	0.	0.	0.
TI	-11811116.	-11510886.	-9878180.	-9978180.	-9528005.
OW	29180088.	29180088.	29180088.	29180088.	29180088.
LF	65958412.	56080232.	46202052.	36323872.	26445692.
TOT1	86697026.	75382140.	65503960.	55625780.	46097775.
STB	0.	0.	0.	0.	0.
BVA	67807880.	62964460.	58121640.	53277620.	48434200.
VI					1000000.
GR					100981192.
INS	1165531.	1165531.	1165531.	1165531.	1165531.
M					4166250.
LA					5000000.
NR	90649419.	90649419.	90649419.	90649419.	90649419.
OCA					2283587.
MO					320077.
OCT					4963000.
TH					625336.
OCF					15000000.
PC					1665000.
WPA					1000007.
D	4843420.	4843420.	4843420.	4843420.	4843420.
TMC	0.	0.	0.	0.	0.
IC	5490852.	4594621.	3696164.	2905910.	2115655.
PBT	48230131.	49136362.	50024818.	50815073.	51605327.
TCD	0.	0.	0.	0.	0.
PBT1	48230131.	49136362.	50024818.	50815073.	51605327.
TE	24115065.	24568181.	25012409.	25407536.	25802663.
PAT	24115065.	24568181.	25012409.	25407536.	25802663.
D	4843420.	4843420.	4843420.	4843420.	4843420.
CG	28958485.	29411601.	29855829.	30250956.	30646083.
DRL	9878180.	9878180.	9878180.	9878180.	9528005.
DRS	1932938.	1636706.	0.	0.	0.
CS	17147367.	17896715.	19077649.	20372776.	21118072.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	34.000	46.000	52.000	56.000	58.000
RI	12.000	16.000	18.000	20.000	22.000

ELEMENT	11	12	13	14	15
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTBI	0.	0.	0.	0.	0.
TI	-9177830.	-7739856.	0.	0.	0.
OW	29180088.	29180088.	29180088.	29180088.	29180088.
LTB	16917667.	7739857.	1.	1.	1.
TOTI	36919945.	29180089.	29180089.	29180089.	29180089.
STO	0.	0.	0.	0.	0.
BVA	43550710.	38747360.	32603940.	29060520.	24217100.
VT					1000000.
GR					100981199.
INS	1165531.	1165531.	1165531.	1165531.	1165531.
M					4166250.
LA					5000000.
NR	90649419.	90649419.	90649419.	90649419.	90649419.
OCN					2983580.
MO					320077.
OCT					4963000.
TH					6253363.
OCP					15000000.
PO					1665000.
WPA					1000000.
D	4843420.	4843420.	4843420.	4843420.	4843420.
TMC	0.	0.	0.	0.	0.
IE	1353415.	619189.	0.	0.	0.
PBT	52367568.	53101794.	53720982.	53720982.	53720982.
TCD	0.	0.	0.	0.	0.
PBTI	52367568.	53101794.	53720982.	53720982.	53720982.
TE	26183784.	26550897.	26860491.	26860491.	26860491.
PAT	26183784.	26550897.	26860491.	26860491.	26860491.
D	4843420.	4843420.	4843420.	4843420.	4843420.
CG	31027204.	31394317.	31703911.	31703911.	31703911.
DRL	9177830.	7739856.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	21849374.	23654461.	31703911.	31703911.	31703911.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	58.000	60.000	60.000	60.000	60.000
RI	22.000	24.000	24.000	24.000	24.000

ELEMENT	16	17	18	19	20
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTM1	0.	0.	0.	0.	0.
TI	0.	0.	0.	0.	0.
OW	29180088.	29180088.	29180088.	29180088.	29180088.
LT	1.	1.	1.	1.	1.
TOT1	29180089.	29180089.	29180089.	29180089.	29180089.
STM	0.	0.	0.	0.	0.
BVA	19373680.	14530260.	9686840.	4843420.	0.
VT					1000000.
GR					100981199.
ING	1165531.	1165531.	1165531.	1165531.	1165531.
M					4166250.
LA					5000000.
NR	90649419.	90649419.	90649419.	90649419.	90649419.
OCM					2983580.
MO					320077.
OCT					4963000.
TR					6253360.
OCP					15000000.
PC					1665000.
WPA					1000000.
D	4843420.	4843420.	4843420.	4843420.	4843420.
TMC	0.	0.	0.	0.	0.
IE	0.	0.	0.	0.	0.
PBT	53720982.	53720982.	53720982.	53720982.	53720982.
TCD	0.	0.	0.	0.	0.
PBT1	53720982.	53720982.	53720982.	53720982.	53720982.
TE	26860491.	26860491.	26860491.	26860491.	26860491.
PAT	26860491.	26860491.	26860491.	26860491.	26860491.
D	4843420.	4843420.	4843420.	4843420.	4843420.
CG	31703911.	31703911.	31703911.	31703911.	31703911.
DRL	0.	0.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	31703911.	31703911.	31703911.	31703911.	31703911.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	60.000	60.000	60.000	60.000	60.000
RI	26.000	26.000	26.000	26.000	26.000

ELEMENT	1	2	3	4	5
TA	2100000.	2100000.	21146095.	139914858.	0.
WC	2100000.	2775888.	7819139.	35418585.	0.
O	1398600.	1398600.	9386519.	43723393.	0.
LTB1	2801400.	2801400.	18801226.	131170178.	0.
TI	4200000.	3849825.	27487395.	175743714.	-20746990.
OW	1398600.	2797200.	12183719.	55907112.	55907112.
LTB	2801400.	5602800.	24053851.	154523678.	151473176.
TOTI	4200000.	8049825.	35637219.	211280932.	190533942.
STB	0.	0.	0.	3900646.	0.
BVA	1995000.	3879474.	24498931.	154742390.	145070992.
VT					15000000.
GR					151471798.
INS	0.	0.	0.	2469086.	2469086.
M					6749375.
LA					7500000.
NR	0.	0.	0.	0.	135253340.
OCR					4183580.
MO					464377.
OCI					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	105000.	215526.	526637.	9671399.	9671399.
TMC	1200000.	1200000.	4754609.	21437748.	0.
IE	224112.	448224.	1924308.	12361894.	12351893.
PBT	-1529112.	-1863750.	-7205555.	-45940127.	64156216.
TCD	1529112.	3392862.	10598417.	56538544.	0.
PBT1	-1529112.	-1863750.	-7205555.	-45940127.	7617671.
TE	0.	0.	0.	0.	3808836.
PAT	-1529112.	-1863750.	-7205555.	-45940127.	60347380.
D	105000.	215526.	526637.	9671399.	9671399.
CG	-1424112.	-1648224.	-6678917.	-36268728.	70018779.
DRL	0.	350175.	700350.	3050503.	19446775.
DRS	0.	0.	0.	0.	1300215.
CS	0.	0.	0.	0.	49271789.
CD	1424112.	1998399.	7379267.	39319231.	0.
WC	2100000.	2775888.	7819139.	35418585.	0.
RO	.000	.000	.000	.000	-10.000
RI	.000	.000	.000	.000	.000

ELEMENT	6	7	8	9	10
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LTD1	0.	0.	0.	0.	0.
TI	-20746990.	-20746990.	-19446775.	-19446775.	-19096600.
OW	55907112.	55907112.	55907112.	55907112.	55907112.
LTD	132026402.	112579627.	93132852.	73686077.	54239302.
TOT1	169786952.	149039962.	129593188.	110146413.	91049813.
STD	0.	0.	0.	0.	0.
BVA	135399594.	125728196.	116056797.	106385398.	96713999.
VT					1500000.
GR					151471799.
INS	2469086.	2469086.	2469086.	2469086.	2469086.
M					6249375.
LA					7500000.
NR	135253340.	135253340.	135253340.	135253340.	135253340.
OCM					4183580.
MO					464377.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	9671399.	9671399.	9671399.	9671399.	9671399.
TMC	0.	0.	0.	0.	0.
IE	10718138.	9084363.	7450628.	5894886.	4339144.
PBT	65789972.	67423726.	69057482.	70613224.	72168966.
TCD	0.	0.	0.	0.	0.
PBT1	65789972.	67423726.	69057482.	70613224.	72168966.
TE	32894986.	33711863.	34528741.	35306612.	36084483.
PAT	32894986.	33711863.	34528741.	35306612.	36084483.
D	9671399.	9671399.	9671399.	9671399.	9671399.
CG	42566385.	43383262.	44200140.	44978011.	45755882.
DRL	19446775.	19446775.	19446775.	19446775.	19096600.
DRS	1300215.	1300215.	0.	0.	0.
CS	21819395.	22636272.	24753365.	25531236.	26659282.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	16.000	28.000	36.000	42.000	44.000
RI	8.000	10.000	14.000	14.000	16.000

ELEMENT	11	12	13	14	15
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTW1	0.	0.	0.	0.	0.
TI	-18746425.	-16396272.	0.	0.	0.
OW	55907112.	55907112.	55907112.	55907112.	55907112.
LTD	35142702.	16396277.	5.	5.	5.
TOTI	72303388.	55907116.	55907116.	55907116.	55907116.
STG	0.	0.	0.	0.	0.
BVA	87042600.	77371201.	67699802.	58028403.	48357004.
VI					1500000.
GR					151471798.
INS	2469086.	2469086.	2469086.	2469086.	2469086.
M					6249375.
LA					7500000.
NR	135253340.	135253340.	135253340.	135253340.	135253340.
OCM					4183580.
MO					464377.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	9671399.	9671399.	9671399.	9671399.	9671399.
TMC	0.	0.	0.	0.	0.
IE	2811416.	1311702.	0.	0.	0.
PBT	73696694.	75196408.	76508110.	76508110.	76508110.
TCD	0.	0.	0.	0.	0.
PBT1	73696694.	75196408.	76508110.	76508110.	76508110.
TE	36848347.	37598204.	38254055.	38254055.	38254055.
PAT	36848347.	37598204.	38254055.	38254055.	38254055.
D	9671399.	9671399.	9671399.	9671399.	9671399.
CG	46519746.	47269603.	47925454.	47925454.	47925454.
DRL	18746425.	16396272.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	27773321.	30873331.	47925454.	47925454.	47925454.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	46.000	46.000	48.000	48.000	48.000
RI	16.000	18.000	18.000	18.000	20.000

ELEMENT	16	17	18	19	20
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTW1	0.	0.	0.	0.	0.
TI	0.	0.	0.	0.	0.
OW	55907112.	55907112.	55907112.	55907112.	55907112.
LTW	5.	5.	5.	5.	5.
TOTI	55907116.	55907116.	55907116.	55907116.	55907116.
STW	0.	0.	0.	0.	0.
BVA	38685605.	29014206.	19342807.	9671407.	0.
VT					1500000.
GR					151471798.
INS	2469086.	2469086.	2469086.	2469086.	2469086.
M					6249375.
LA					7500000.
NR	135253340.	135253340.	135253340.	135253340.	135253340.
OCM					4183580.
MO					464377.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	9671399.	9671399.	9671399.	9671399.	9671399.
TMC	0.	0.	0.	0.	0.
IE	0.	0.	0.	0.	0.
PBT	76508110.	76508110.	76508110.	76508110.	76508110.
TCD	0.	0.	0.	0.	0.
PBT1	76508110.	76508110.	76508110.	76508110.	76508110.
TL	38254055.	38254055.	38254055.	38254055.	38254055.
PAT	38254055.	38254055.	38254055.	38254055.	38254055.
D	9671399.	9671399.	9671399.	9671399.	9671399.
CG	47925454.	47925454.	47925454.	47925454.	47925454.
DRL	0.	0.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	47925454.	47925454.	47925454.	47925454.	47925454.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	50.000	50.000	50.000	50.000	50.000
RI	20.000	20.000	20.000	20.000	20.000

ELEMENT	1	2	3	4	5
TA	2100000.	2100000.	14646095.	80514859.	0.
WC	2100000.	2775888.	5738064.	20128715.	0.
O	1398600.	1398600.	6456852.	25160893.	0.
LTL1	2801400.	2801400.	12933093.	75482680.	0.
TI	4200000.	3996550.	19210686.	104773174.	-9854141.
OW	1398600.	2797200.	9954052.	34414945.	34414945.
LTL	2801400.	5602800.	18702443.	93318223.	91773566.
TOTI	4200000.	8196550.	27777236.	132150410.	122296270.
STB	0.	0.	287641.	5770138.	0.
BVA	1995000.	3879474.	17698932.	92624744.	86935698.
VT					1500000.
GR					151471798.
INS	0.	0.	0.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	0.	0.	0.	0.	136301574.
OCF					2803587.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	105000.	215526.	526637.	5789046.	5789046.
TMC	1200000.	1200000.	4094609.	15354748.	0.
IE	224112.	448224.	1464195.	7482716.	7699599.
PBT	-1529112.	-1863750.	-6085442.	-30047361.	75183396.
TCD	1529112.	3392862.	9478304.	39525666.	0.
PBT1	-1529112.	-1863750.	-6085442.	-30047361.	35657730.
TE	0.	0.	0.	0.	17828865.
PA1	-1529112.	-1863750.	-6085442.	-30047361.	57354531.
D	105000.	215526.	526637.	5789046.	5789046.
CG	-1424112.	-1648224.	-5558805.	-24258315.	63143577.
DRL	0.	233450.	466900.	1544658.	7834881.
DRS	0.	0.	0.	95880.	2019260.
CS	0.	0.	0.	0.	53289437.
CD	1424112.	1881674.	6025705.	25898853.	0.
WC	2100000.	2775888.	5738064.	20128715.	0.
RO	.000	.000	.000	.000	34.000
RI	.000	.000	.000	.000	10.000

ELEMENT	6	7	8	9	10
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
O	0.	0.	0.	0.	0.
LTG1	0.	0.	0.	0.	0.
TI	-9854141.	-9758260.	-7834881.	-7834881.	-7834881.
CW	34414945.	34414945.	34414945.	34414945.	34414945.
LTG	83938685.	76103804.	68268923.	60434042.	52599161.
TOTI	112442160.	102663870.	94848989.	87014108.	79179227.
STH	0.	0.	0.	0.	0.
BVA	81046652.	75257606.	69468560.	63679514.	57890467.
VT					1500000.
GR					151471798.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	136301574.	136301574.	136301574.	136301574.	136301574.
OCN					2883580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PU					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IE	6951653.	6203707.	5461514.	4834723.	4207933.
PBT	75931342.	76679288.	77421482.	78048272.	78675064.
TCG	0.	0.	0.	0.	0.
PBT1	75931342.	76679288.	77421482.	78048272.	78675064.
TE	37965671.	38339644.	38710741.	39024136.	39337532.
PAT	37965671.	38339644.	38710741.	39024136.	39337532.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	43754717.	44128690.	44499787.	44813182.	45126578.
DRL	7834881.	7834881.	7834881.	7834881.	7834881.
DRS	2019260.	1923379.	0.	0.	0.
CS	33960577.	34370430.	36664906.	36978301.	37291697.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	62.000	74.000	78.000	82.000	82.000
RI	18.000	22.000	26.000	28.000	28.000

ELEMENT	11	12	13	14	15
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LTO1	0.	0.	0.	0.	0.
TI	-7834881.	-7834881.	-7834881.	-7601431.	-7367981.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTO	44764280.	36929399.	29094518.	21259637.	13658206.
TOT1	71344346.	63509465.	55674584.	48073153.	40705172.
STO	0.	0.	0.	0.	0.
BVA	52101421.	46312374.	40523328.	34734281.	28945235.
VT					1500000.
GR					151471798.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	136301574.	136301574.	136301574.	136301574.	136301574.
OCA					2883580.
MO					320077.
OCI					7923000.
TH					10005376.
OCP					22500000.
PO					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IE	3581142.	2954352.	2327561.	1700771.	1092656.
PBT	79301854.	79928644.	80555434.	81182226.	81790340.
TCD	0.	0.	0.	0.	0.
PBT1	79301854.	79928644.	80555434.	81182226.	81790340.
TE	39650927.	39964322.	40277717.	40591113.	40895170.
PAT	39650927.	39964322.	40277717.	40591113.	40895170.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	45439973.	45753368.	46066763.	46380159.	46684216.
DRL	7834881.	7834881.	7834881.	7601431.	7367981.
DRS	0.	0.	0.	0.	0.
CS	37605092.	37918487.	38231882.	38778728.	39316235.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	84.000	84.000	84.000	84.000	84.000
RI	30.000	30.000	30.000	32.000	32.000

ELEMENT	16	17	18	19	20
TA	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
C	0.	0.	0.	0.	0.
LTB1	0.	0.	0.	0.	0.
TI	-6290223.	0.	0.	0.	0.
OW	34414945.	34414945.	34414945.	34414945.	34414945.
LTB	6290225.	2.	2.	2.	2.
TOTI	34414949.	34414949.	34414949.	34414949.	34414949.
STB	0.	0.	0.	0.	0.
BVA	23156188.	17367142.	11576095.	5789049.	3.
VT					1500000.
GR					151471790.
INS	1420850.	1420850.	1420850.	1420850.	1420850.
M					6249375.
LA					7500000.
NR	136301574.	136301574.	136301574.	136301574.	136301574.
OCM					2983580.
MO					320077.
OCT					7923000.
TH					10005376.
OCP					22500000.
PC					2497500.
WPA					1500000.
D	5789046.	5789046.	5789046.	5789046.	5789046.
TMC	0.	0.	0.	0.	0.
IE	503218.	0.	0.	0.	0.
PBT	82379778.	82882996.	82882996.	82882996.	82882996.
TCD	0.	0.	0.	0.	0.
PBTI	82379778.	82882996.	82882996.	82882996.	82882996.
TE	41189889.	41441498.	41441498.	41441498.	41441498.
PAT	41189889.	41441498.	41441498.	41441498.	41441498.
D	5789046.	5789046.	5789046.	5789046.	5789046.
CG	46978935.	47230544.	47230544.	47230544.	47230544.
DRL	6290223.	0.	0.	0.	0.
DRS	0.	0.	0.	0.	0.
CS	40688712.	47230544.	47230544.	47230544.	47230544.
CD	0.	0.	0.	0.	0.
WC	0.	0.	0.	0.	0.
RO	84.000	84.000	84.000	84.000	84.000
RI	32.000	32.000	32.000	32.000	32.000

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